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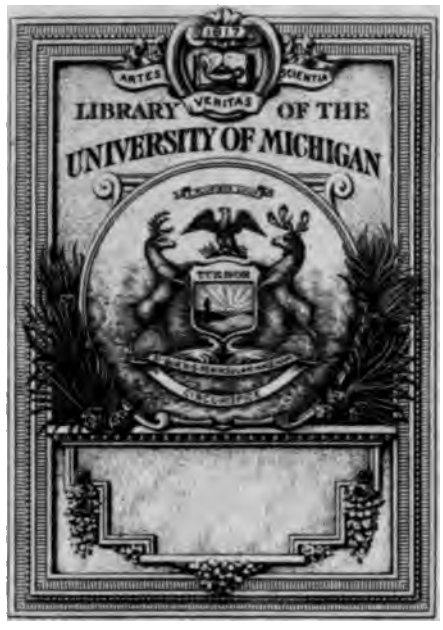

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Reports

THE UNIVERSITY

GEOLOGICAL SURVEY

OF

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CONDUCTED UNDER AUTHORITY OF THE BOARD OF REGENTS OF THE UNIVERSITY OF KANSAS, AS AUTHORIZED BY STATE LEGISLATION.

VOL. IX.

SPECIAL REPORT ON OIL AND GAS.

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State Geologist.

FOR VOLUME IX.

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H. P. CADY, PH. D.,
D. F. McFARLAND, M. A., } *Chemists for Gas Analyses.*
F. W. BUSHONG, *Chemist for Oil Analyses.*

LETTER OF TRANSMITTAL.

Dr. Frank Strong, Chancellor of the University of Kansas:

SIR—I have the honor to submit to you herewith a special report on Oil and Gas of Kansas prepared by the state geologist and his assistants.

This report will constitute volume IX of the Reports of the University Geological Survey of Kansas.

Most respectfully submitted,

ERASMUS HAWORTH,
State Geologist.

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PREFACE.

THE great development in the production of petroleum and natural gas in Kansas and Oklahoma, generally called the Midcontinental field, within the last few years, has made it highly desirable that a carefully prepared report on the subject be published, giving as great detail as possible to all phases of our knowledge bearing upon the occurrence, origin, nature, uses and commerce of these two commodities. This Survey has been collecting data on the subject for more than ten years, and has published, in a fragmentary way, bits of information from time to time in various annual reports on the mineral resources of Kansas. Likewise, the United States Geological Survey has issued a few small publications covering certain phases of the subject. But previously no attempt has been made to treat the entire subject in a comprehensive manner.

In the following pages the order of treatment was arranged from the standpoint of geology, giving first the geography and stratigraphy of the productive formations, next the general and detailed geological conditions under which they occur; and this is followed by an exposition of the chemical and physical properties of oil and gas, their values for various purposes, particularly as heat producers; and lastly, the commercial aspect of the subject, which includes production, market value, probable future development, etc.

As the oil and gas of Kansas occur entirely in the Coal Measures a discussion of their geological relations of course is a discussion of the Coal Measures. Much has been said and written about the stratigraphy of Kansas Coal Measures, in fact, too much.

Years ago this Survey began a systematic study of the detailed stratigraphy of eastern Kansas. Largely because the existence of the Survey depended upon biennial appropriations, preliminary reports were made. Naturally, such reports were somewhat defective. Geologists in neighboring states—Missouri, Iowa, and Nebraska—have taken up the matter in

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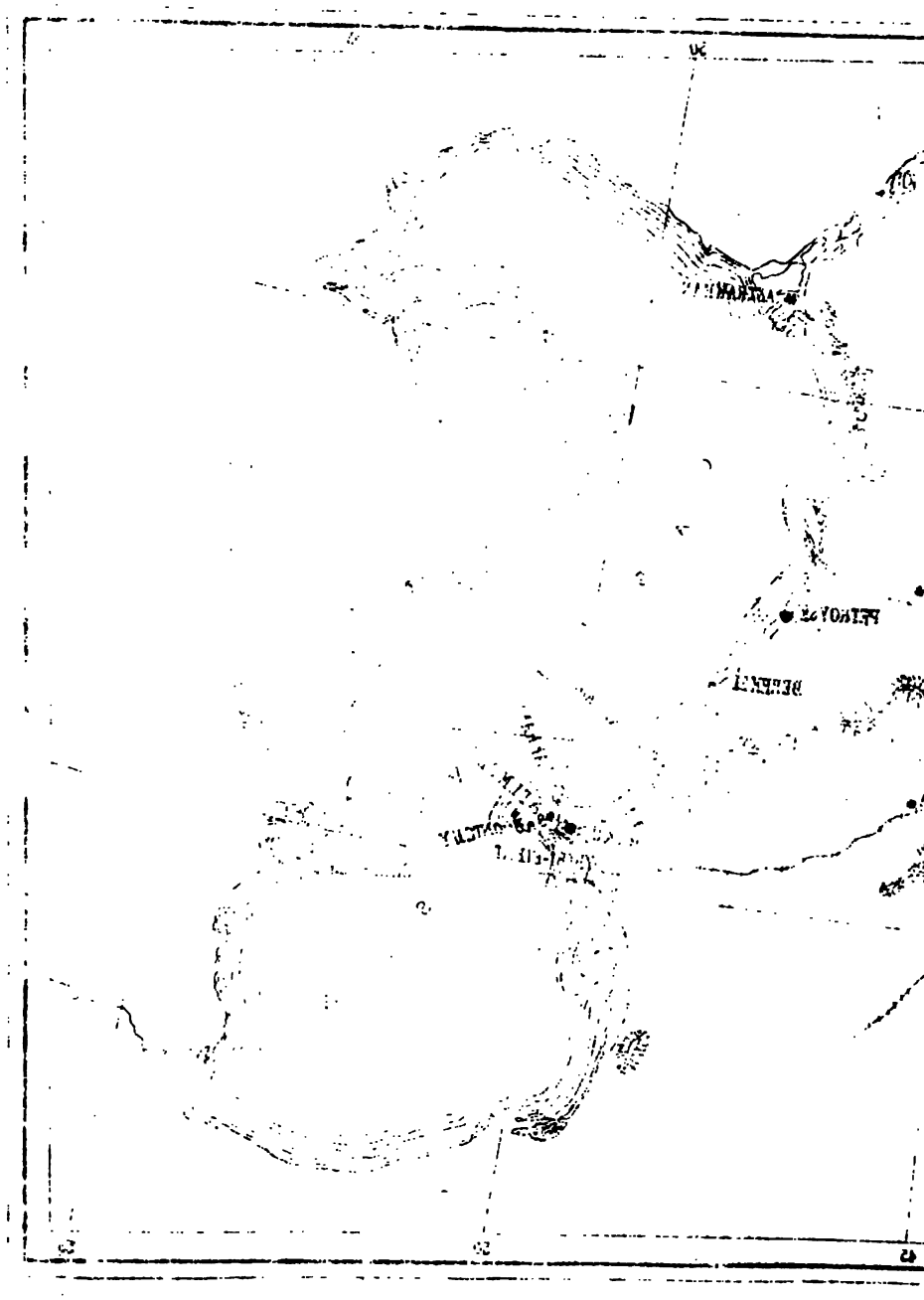

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a way largely by criticism of Kansas rather than by giving details of conditions in their own states which might have been used for comparison, with the result that there is now in print, widely scattered through magazines, state and governmental reports, a comparatively extensive literature on the stratigraphy of the Kansas Coal Measures which is partly correct and partly incorrect. This condition has been aggravated, although wholly unintentionally, through the labors of the United States Geological Survey, which organization has surveyed the Iola quadrangle and Independence quadrangle. An error in stratigraphy was made and published regarding the southwest corner of the Iola quadrangle. Field-work on the Independence quadrangle was conducted and a preliminary report published before this error in the Iola quadrangle was detected, and, as a result, its influence caused errors to creep into the Independence sheets reports as well.

In the present volume the stratigraphy of eastern Kansas is given in great detail after years of continued work, and it is confidently believed we have finally succeeded in getting all matters straightened out so that the presentation here offered is a tolerably complete and accurate exposition of position and relations of all alternating beds of limestones and shales, with included sandstones, from the bottom of the Lower Coal Measures up to the Burlingame limestone. Every individual limestone has been traced with greatest detail by a personal examination, not only of every mile square, but by a geologist following it across every forty-acre tract of land from the north side of the state to the south. In some instances, where difficulties were greatest, two or more geologists have spent weeks and months in tracing such formations a distance of only a few miles.

While this vast amount of field-work has been done under the direction of the state geologist, it is but fair to say that a large part of it, and all of the most difficult parts, has been performed by or under the immediate supervision of John Bennett. He has traveled in greatest detail all along the outcropping lines of practically every limestone in the area mentioned. Ever since the summer of 1894, covering a period of twelve years, he has had this as his one constant theme, and it is no exaggeration to state that there is scarcely a quarter-section of land along the outcropping of any one of these limestones which he has not gone over one or more times. I wish

to express my personal appreciation of this great work performed by him, largely as a matter of love, and to give it as my belief that no piece of work has ever been done by an American geologist more thoroughly or more conscientiously than the work done by Mr. Bennett.

Professors H. B. Cady and D. F. McFarland, of the Chemical Department, University of Kansas, consented to make a series of analyses of Kansas gases, samples of which were furnished them at the expense of the Survey. The investigation proved to be more interesting than anticipated, which resulted in gas samples being gathered practically all the way from the Atlantic to the Pacific oceans; not as many, however, as all of us wished we had time and opportunity to gather. They have written an elaborate report on their work, in which is included a good summary of gas analyses by others, making their chapter one of unusual interest.

In a similar manner Prof. F. W. Bushong, of the Chemical Department, University of Kansas, made an extended series of analyses of oil and wrote a chapter on the same, corresponding in interest to the one just mentioned for natural gas.

In the discussion of location of oil and gas, particularly the latter, it was deemed desirable to give in great detail the natural conditions of occurrence rather than a lengthy discussion of theories as to their origin. The latter question, however, had to be touched upon. It is probable that no one phase of our studies of oil and gas would become of more practical value than the study of their origin, provided we could only reach correct conclusions. But the great difficulty is in knowing that one is correct. If one could positively determine when and where and how these hydrocarbons originated, quite likely one would have a very great advantage in determining their present locations. As a matter of interest, and also of direct value in stratigraphic correlations, a considerable amount of paleontology has been included in the report, which the thoughtful reader will recognize as having great practical value.

ERASMUS HAWORTH,
State Geologist.

and one 200 feet deep, at Makum, produced a hundred gallons an hour. The coasts of Arakan and the adjacent islands have long been famed for mud-volcanoes caused by the eruption of hydrocarbon gases. . . .

For centuries Japan is known to have had oil. Here, as elsewhere in the Orient, it existed long before any special use, in the modern sense of the term, was made of it. Representatives of the Standard Oil Company and other Americans have invaded the Japanese islands and made comparatively large investments with fairly good returns, although the total production of oil from Japan has never reached large enough figures to have much influence on the markets of the world.

Russia is the greatest of all foreign countries in the production of oil, and is so exceedingly productive that it rivals America. Oil and gas have been known in this part of the world as long as we have authentic history, and probably it was known to the natives in prehistoric times. The territory thus far developed is small and the most remarkable in all the world, if judged by prodigious production. Wells producing 10,000 barrels per day are known—wells which so far outstrip the greatest in other parts of the world that by comparison they are giants. The gas-pressure which throws the oil from the wells is as great, or greater, than that exhibited in the early days of Pennsylvania.

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"The natural gas exudations and the petroleum deposits of the Apsheron peninsula have been known for many centuries; indeed, it is asserted that the existing site of the temple of fire-worshipers, situated near the extremity of the peninsula, at Surakhany, has been frequented by Parsee devotees for more than 2500 years, and, according to the statement of the British consul at Batoum, the last priest departed only a few years ago. It is also affirmed by historians that the Baku petroleum has for centuries been collected by the Persians and sent into the interior of Persia and India, where the white variety, found in some districts, was employed as a medicine for curing divers internal complaints, or applied externally as a dressing for relieving irritant sores, etc.; but there is little evidence to show that the common 'crude' was used as an illuminant or a source of heat, except in the form of briquettes made by mixing the oil with ashes or earth. In 1723 Baku was annexed by Peter the Great, but in 1735 the territory was restored to Persia, being eventually reoccupied by Russia in 1806.

"When Russia took possession of Baku a second time there was a small trade in oil, and the government, after deliberation, granted to a merchant named Meerzoeff a monopoly for extracting oil from the petroleum deposits, in return for payment of a royalty on all oil raised, the effect of which was to restrict the output of petroleum, which, in 1872, only amounted to about 1,500,000 poods per annum. A popular demand for the abolition of the monopoly arose, to which the government ultimately assented (1872) but its removal was followed by the imposition of a tax in the form of excise duty. The oil industry showed a marked improvement under the altered conditions, although still impeded from full development, but in 1877 the excise duty was also canceled, and the business, freed from all restrictions, rapidly increased in magnitude and importance.

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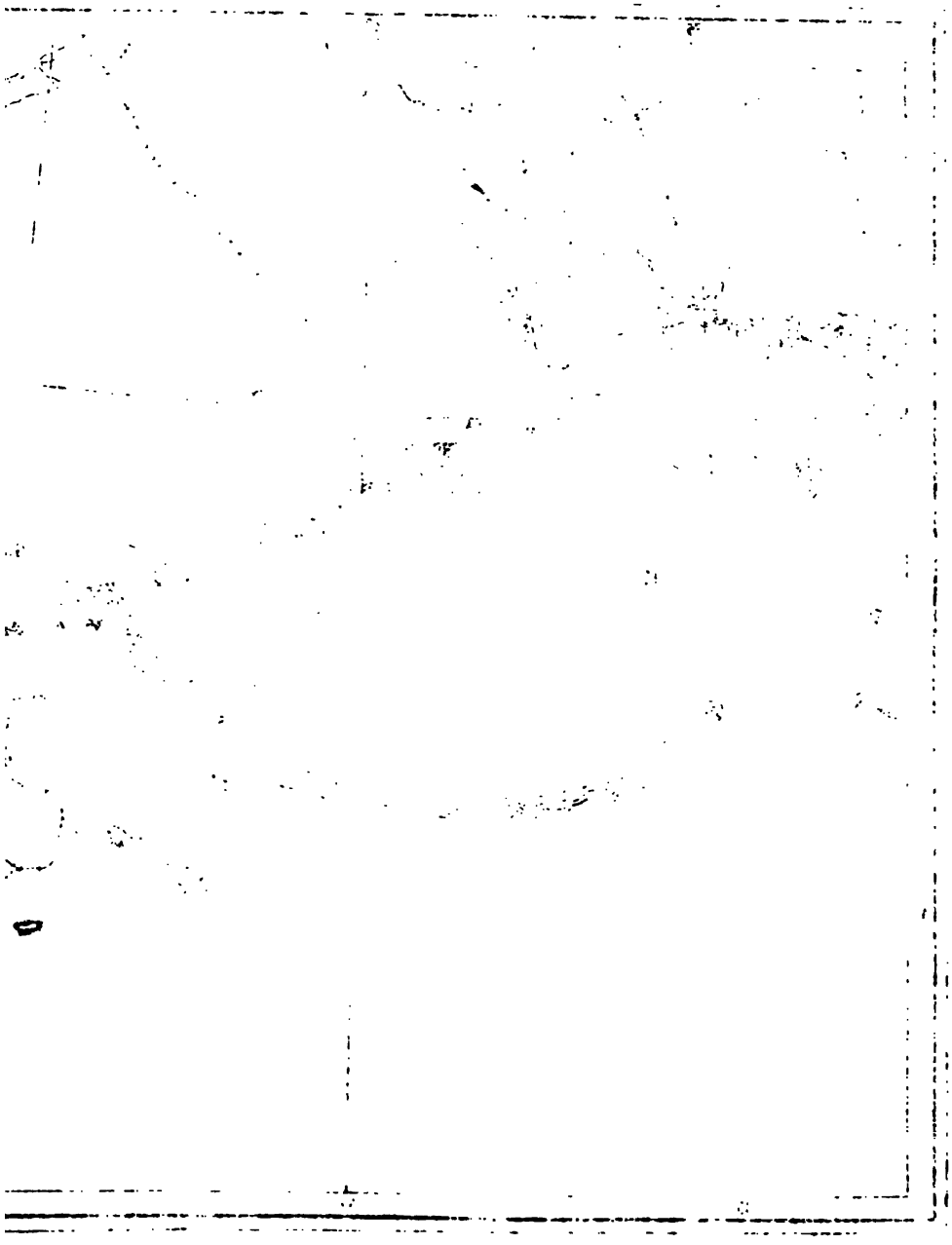

CHAPTER I.

DISCOVERIES OF OIL AND GAS. GEOGRAPHICAL AND HISTORICAL.

By Erasmus Haworth.

ONE of the most difficult facts of history to understand in the industrial development of the world is the extreme slowness with which the human race really began using oil and gas in a commercial way. History fails to record when the first discoveries of these hydrocarbons were made by the human family. They were known and were used in a small way by different peoples scattered almost all over the face of the earth long before the times of our early written history. Their existence has had a great influence on the human race throughout all this time; the oil being used for medicine, some grades of tar and asphaltum being used for different kinds of cement; and the natural gas exuding from the ground probably constituted all or nearly all of the sacred fires worshiped by different peoples at different times.

Yet, with all this knowledge of so long duration, it was not until the famous Drake well was drilled in Pennsylvania, in 1859, that any use, in the modern sense of the term, was made of petroleum or any of its products. Mr. J. J. McLaurin, of Franklin, Pa., has published a book entitled Sketches in Crude Oil, from which a few extracts may well be taken to set forth some of the earlier discoveries of oil.

". . . The fountains of Is, on the Euphrates, were familiar to the founders of Babylon, who secured indestructible mortar for the walls of the city by pouring melted asphaltum between the blocks of stone. These famous springs attracted the attention of Alexander, Trajan and Julian. Even now asphaltum procured from them is sold in the adjacent villages. The commodity is skimmed off the saline and sulphurous waters and solidified by evaporation. The ancient Egyptians used another form of the same substance in preparing mummies, probably obtaining their supplies from a spring on the Island of Zanta, described by Herodotus. . . .

"Asphaltum is found in the Dead Sea, the supposed site of Sodom and Gomorrah, and on the surface of a chain of springs along its banks, far below the level of the ocean. Strabo referred to this remarkable feature 2000 years ago. The destruction of the two ill-fated cities may have been connected with, if not caused by, vast natural stores of this inflammable petroleum. The immense accumulations of hardened rock-oil in the center and on the banks of the sea were oxidized into resin-like asphalt. Pieces picked up from the waters are frequently carved, in the convents of Jerusalem, into ornaments, which retain an oily flavor. Aristotle, Josephus and Pliny mention similar deposits at Albania, on the shores of the Adriatic. Dioscorides Pedanius, the Greek historian, tells how the citizens of Agrigentum, in Sicily, burned petroleum in rude lamps prior to the birth of Christ. For two centuries it lighted the streets of Genoa and Parma, in northern Italy. Plutarch describes a lake of blazing petroleum near Ecbatana. Persian wells have produced oil liberally for ages, under the name of 'naphtha,' the descendants of Cyrus, Darius and Xerxes consuming the fluid for its light. The earliest records of China refer to petroleum, and small quantities have been found in Thibet. An oil-fountain on one of the Ionian islands has gushed steadily for over twenty centuries without once going on a strike or taking a vacation. Austria and France likewise possess oil-springs of considerable importance. Thomas Shirley, in 1667, tested the contents of a shallow pit in Lancashire, England, which burned readily. Rev. John Clayton visited it and wrote in 1691: 'I saw a ditch where the water burned like brandy. Country-folk boil eggs and meat in it.'

"Near Bitche, a small fort perched on the top of a peak at the entrance of one of the defiles of Lorraine opening into the Vosges mountains—a fort which was of great embarrassment to the Prussians in their last French campaign—and in the valley guarded by this fortress, stand the chateau and village of Walsbroun, so named from a strange spring in the forest behind it. In the middle ages this fountain was famous. Inscriptions, ancient coins and the relics of a Roman road attest that it had been celebrated even in earlier times. In the sixteenth century a basin and bath for sick people existed. No record of its abandonment has been preserved. In the last century it was rediscovered by a medical antiquarian, who found the naphtha, or white petroleum, almost exhausted. . .

"Around the volcanic isles of Cape Verde oil floats on the water, and to the south of Vesuvius rises through the Mediterranean, exactly as when 'the morning stars sang together.' Hanover, in Germany, boasts the most northerly of European 'earth-oils.' The islands of the Ottoman archipelago and Syria are richly endowed with the same product. Roumania is literally flowing with petroleum, which oozes from the Carpathians and pollutes the water-springs. Turkish domination has hin-

dered the development of the Roumanian region. Southern Australia is blessed with bituminous shales, resembling those in Scotland, good for sixty gallons of petroleum to the ton. The New Zealanders obtained a meager supply from the hillsides, collecting carefully the droppings from the interior rocks, and several test-wells have resulted satisfactorily. The unsophisticated Sumatrans . . . stick pipes in rocks and hills that trickle petroleum and let the liquid drop upon their heads until their bodies are sleek and slippery as an eel. . .

"The Rangoon district of India long yielded 400,000 hogsheads annually, the Hindoos using the oil to heal diseases, to preserve timber and to cremate corpses. Burma has been supplied from this source for an unknown period. The liquid, which is of a greenish-brown color and resembles lubricating-oil in density, gathers in pits sunk twenty to ninety feet in beds of sandy clays overlying slates and sandstones. Clumsy pots or buckets, operated by quaint windlasses, hoist the oil slowly to the mouth of the pits, whence it is carried across the country in leathern bags borne on men's shoulders, or in earthen jars packed into carts drawn by oxen. Major Michael Symes, ambassador to the court of Ava in 1765, published a narrative of his sojourn, in which is this passage:

" 'We rode until two o'clock, at which hour we reached Yaynangheomn, or Petroleum creek. . . . The smell of the oil is extremely offensive. It was nearly dark when we approached the pits. There seemed to be a great many pits within a small compass. Walking to the nearest, we found the aperture about four feet square and the sides lined, as far as we could see down, with timber. The oil is drawn up in an iron pot, fastened to a rope passed over a wooden cylinder, which revolves on an axis supported by two upright posts. When the pot is filled, two men take hold of the rope by the end and run down a declivity, which is cut in the ground, to a distance equal to the depth of the well. When they reach the end of the track the pot is raised to its proper elevation; the contents, water and oil together, are discharged into a cistern, and the water is afterward drawn through a hole in the bottom. . . . When a pit yielded as much as came up to the waist of a man it was deemed tolerably productive; if it reached his neck it was abundant, and that which reached no higher than his knee was accounted indifferent.'

"Labor-saving machinery has not forged to the front to any great degree in the oil-fields of the East Indies. For the Burmese trade flatboats ascend the Irrawaddy to Rainanghong, a town inhabited almost exclusively by the potters who make the earthen jars in which the oil is kept for this peculiar traffic. . . . Petroleum in India occurs in middle or lower Tertiary rock. In the Rawalpindi district of the Panjab it is found at sixteen localities. At Gunda a well yielded eleven gallons a day for six months, from a boring eighty feet deep,

and one 200 feet deep, at Makum, produced a hundred gallons an hour. The coasts of Arakan and the adjacent islands have long been famed for mud-volcanoes caused by the eruption of hydrocarbon gases. . . .

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flannel cloth, retorted hotly: 'I 'm no blanked fool to dig a hole for the oil to get away through the bottom.' . . .

"Kentucky, the home of James Harrod and Daniel Boone, Henry Clay and George D. Prentice, was noted for other things besides backwoods fighters, statesmanship, sparkling journalism, thoroughbred horses, superb women and moonshine whisky. Off in the southeast corner of Wayne county, near the northeast corner of a 6000-acre tract of wild land, David Beatty bored a well for salt about the year 1818. The land extended four miles westward from the Big South Fork of the Cumberland river, its eastern boundary, and three miles down the Fork from Tennessee, its southern line. The well was located on a strip of flat ground between the stream and a rocky bluff, streaked with veins of coal and limestone. Five yards from the water a hole nine feet square was dug ten feet to the rock and timbered. The well, barely three inches in diameter, was punched 170 feet by manual labor, steam-engines not having penetrated the trackless forests of Wayne at that period. To the intense disgust of the workmen a black, sticky, viscid liquid persisted in coming up with the salt-water and a new location was chosen two miles farther down the creek. Extra care not to drill too deep averted an influx of the disagreeable fluid which spoiled the first venture. Salt-works were established and flourished for years, a simon-pure oasis in the interminable wilderness. . . .

"The abandoned well did not propose to be snuffed out unceremoniously or to enact the role of 'Leah the Forsaken.' In its bright lexicon the word 'fail' was not to be inserted merely because it was too fresh to participate in the salt trade. Far from retiring permanently, it spouted petroleum at a Nancy-Hanks quickstep, filling the pit, running into the Fork and covering mile after mile of the water with a top-dressing of oil. Somehow the floating mass caught fire and mammoth pyrotechnics ensued. The stream blazed and boiled and sizzled from the well to the Cumberland river, thirty-five miles northward, calcining rocks and licking up babbling brooks on its fiery march. Trees on its banks burned and blistered and charred to their deepest roots. Iron pans at the salt-wells got red hot, shriveled, warped, twisted, and joined the junk-pile. Was not that a sweet revenge for plucky No. 1, the well its owner 'had no use for' and devoutly wished at the bottom of the sea?"

Late in the '50's the real commercial importance of petroleum began to present itself to the minds of influential men in eastern United States. This was particularly true with reference to one George H. Bissell, who became so impressed with the idea that oil would be valuable commercially, if obtained in sufficient quantities, that largely through his endeavors a

of oil, in what is now New York, known to the Indians and by them given a name signifying 'plenty there.' Likely this was the petroleum occupying the cavities in fossils at Black Rock, below Buffalo, in sufficient abundance to be an object of commerce. Concerning the celebrated oil-spring of the Seneca Indians, near Cuba, N. Y., which D'Allion may also have seen, Prof. Benjamin Silliman, in 1833, said:

" 'This is situated in the western part of the county of Allegany, in the state of New York. This county is the third from Lake Erie on the south line of the state, the counties of Cattaraugus and Chautauqua lying west and forming the southwestern termination of the state of New York. The spring is very near the line which divides Allegany and Cattaraugus. . . . The country is rather mountainous, but the road running between the ridges is very good and leads through a cultivated region rich in soil and picturesque in scenery. Its geographical formation is the same as that which is known to prevail in the western region; a silicious sandstone with shale, and in some places limestone, is the immediate basis of the country. . . . The oil-spring or fountain rises in the midst of a marshy ground. It is a muddy, dirty pool of about eighteen feet in diameter and is nearly circular in form. There is no outlet above ground, no stream flowing from it, and it is, of course, a stagnant water, with no other circulation than that which springs from the changes in temperature and from the gas and petroleum that are constantly rising through the pool.

" 'We are told that the odor of petroleum is perceived at a distance in approaching the spring. This may be true in particular states of the wind, but we did not distinguish any peculiar smell until we arrived on the edge of the fountain. Here its peculiar character became very obvious. The water is covered with a thin layer of petroleum or mineral oil, as if coated with dirty molasses, having a yellowish-brown color.

" 'They collect the petroleum by skimming it like cream from a milk-pan. For this purpose they use a broad, flat board, made thin at one edge like a knife; it is moved flat upon and just under the surface of the water and is soon covered by a coating of petroleum, which is so thick and adhesive that it does not fall off, but is removed by scraping the instrument upon the lip of a cup. It has then a very foul appearance, but it is purified by heating and straining it while hot through flannel. It is used by the people of the vicinity for sprains and rheumatism and for sores on their horses.'

"The 'muddy, dirty pool' was included in an Indian reservation, one mile square, leased in 1860 by Allen, Bradley & Co., who drove a pipe into the bog. At thirty feet oil began to spout to the tune of a barrel an hour, a rhythm not unpleasing to the owners of the venture. The flow continued several weeks and then 'stopped short, never to go again.' Other wells

followed to a greater depth, none of them proving sufficiently large to give the field an orchestra chair in the petroleum arena. . . .

"The history of petroleum in America commences with the use the pioneer settlers found the redmen made of it for medicine and for painting their dusky bodies. The settlers adopted its medicinal use and retained for various affluents of the Allegheny the Indian name of Oil creek. Both natives and whites collected the oil by spreading blankets on the marshy pools along the edges of the bottom-lands at the foot of steep hillsides or of mountain walls that hem in the valleys supporting coal-measures above. The remains of ancient pits on Oil creek—the Oil creek ordained to become a household word—lined with timbers and provided with notched logs for ladders, show how for generations the aborigines had valued and stored the product. Some of these queer reservoirs, choked with leaves and dirt accumulated during hundreds of years, bore trees two centuries old. Many of them, circular, square, oblong and oval, sunk in the earth fifteen to twenty feet and strongly cribbed, have been excavated. Their number and systematic arrangement attest that petroleum was saved in liberal quantities by a race possessing in some degree the elements of civilization. The oil has preserved the timbers from the ravages of decay, 'to point a moral or adorn a tale,' and they are as sound to-day as when cut down by hands that crumbled into dust ages ago. . . .

"The renowned 'spring' which may have supplied these remarkable vats was located in the middle of Oil creek, on the McClintock farm, three miles above Oil City and a short distance below Rouseville. Oil would escape from the rocks and gravel beneath the creek, appearing like air-bubbles until it reached the surface and spread a thin film reflecting all the colors of the rainbow. From shallow holes, dug and walled sometimes in the bed of the stream, the oil was skimmed and husbanded jealously. The demand was limited and the enterprise to meet it was correspondingly modest. Nathaniel Cary, the first tailor in Franklin and owner of the tract adjoining the McClintock, peddled it about the townships early in the century, when the population was sparse and every good housewife laid by a bottle of 'Seneca Oil' in case of accident or sickness. Cary would sling two jars or kegs across a faithful horse, and, mounting this willing steed, went his rounds at irregular intervals. Occasionally he took a ten-gallon cargo to Pittsburg, riding with it eight miles on horseback and trading the oil for cloth and groceries. His memory should be cherished as the first 'shipper' of petroleum to 'the Smoky City,' then a mere cluster of log and frame buildings in a patch of cleared ground surrounding Fort Pitt. . . .

"Signs of petroleum in the Keystone state were not confined to Oil creek. Ten miles westward, in water-wells and in the

bed and near the mouth of French creek, the indications were numerous and unmistakable. The first white man to turn them to account was Marcus Hulings, of Franklin, the original Charon of Venango county. Each summer he would skim a quart or two of 'earth-oil' from a tiny pond formed by damming a bit of the creek, the fluid serving as a liniment and medicine. . . .

"Excavating for the Franklin canal in 1832, on the north bank of French creek, opposite 'the infant industry' of Hulings forty years previously, the workmen were annoyed by a persistent seepage of petroleum, execrating it as a nuisance. A well dug on the flats ten years later, for water, encountered such a glut of oil that the disgusted wielder of the spade threw up his job and threw his besmeared clothes into the creek! When the oil excitement invaded the county-seat the greasy well was drilled to the customary depth and proved hopelessly dry. At Slippery Rock, in Beaver county, oil exuded abundantly from the sandy banks and bed of the creek, failing to pan out when wells were put down. Something of the same sort occurred in portions of Lawrence county and on the banks of many streams in different sections of the country. . . .'

In early days in America, people living back some distance from tide-water were greatly inconvenienced by not having a good supply of salt. This led to many attempts, successful and otherwise, to obtain brine by boring or drilling, from which salt could be produced by evaporation. These old salt-wells really should be looked upon as the precursors of oil-wells. Some of these earliest borings were along the Kanawha river in West Virginia. Quoting again from McLaurin:

"Dr. J. P. Hale, a reputable authority, claims oil caused much annoyance in Ruffner Bros.' salt-well, begun in 1806, bored sixty feet with an iron rod and a two-inch chisel-bit attached by a rope to a spring-pole, completed in 1808 and memorable as the *first artesian well* on this continent. The fluid came from the territory once famous as the 'Kanawha salines,' reputed to produce an unsurpassed table salt. Before the advent of the white man the Indians made salt from the saline springs a short distance above the site of Charleston. There Daniel Boone had a log cabin, and George Washington, as long ago as 1775, for military services was awarded lands containing a 'burning spring.' Fired by the tidings of the saline springs, Joseph Ruffner sold his possessions in the Shenandoah valley and journeyed beyond the mountains in 1794 to establish salt-works on the Kanawha. He leased the salt interest to Elisha Brooks, who took brine from the shallow quicksands. Joseph Ruffner dying, his sons, Joseph and David, acquired his lands and salt-springs and resolved to try some better plan of procuring the brine. A section of a hollow syca-

more tree, sunk into the quicksands, suggested the idea of wooden casing and the wisdom of boring a little way from the spring. A piece of oak, bored from end to end as log pumps used to be, was set in the hole. The ingenious brothers devised a chisel-like drill to pierce the rock, fastened it to a rope fixed to a spring-pole, and bounced the tool briskly. To shut out the weak brine above from the strong brine beneath, they put in tin tubing, around which they tied a leather bag filled with flaxseed. Thus, three generations ago, Joseph and David Ruffner, aided later by William Morris and his invention of 'jars' in drilling-tools, stumbled upon the basis of casing, seed-bagging and boring oil-wells. All honor to the memory of these worthy pioneers, groping in the dark to clear the road for the great petroleum boom. Doctor Hale continues:

" 'Nearly all the Kanawha salt-wells have contained more or less petroleum, and some of the deeper wells a considerable flow. Many persons now think, trusting to their recollections, that some of the wells afforded as much as twenty-five to fifty barrels per day. This was allowed to flow over from the top of the salt-cisterns to the river, where, from its specific gravity, it spread over a large surface, and by its beautiful iridescent hues and not very savory odor could be traced for many miles down the stream. It was from this that the river received the nickname of "Old Greasy," by which it was long known by Kanawha boatmen and others.' "

Drilling for salt-wells was by no means confined to Pennsylvania and West Virginia. To the west, in Ohio, the same kind of enterprises were engaged in, with results similar to those obtained in Pennsylvania. Quoting again from McLaurin:

"On an old map of the United States, printed in England in 1787, the word 'petroleum' is marked twice, indicating that the 'surface-shows' of oil had attracted the notice of the earliest explorers of southern Ohio and northwestern Pennsylvania a century ago. In one instance it is placed at the mouth of the stream since famed the world over as Oil creek, where Oil City is situated; in the other, on a stream represented as emptying into the Ohio river, close to the site of what is now the village of Macksburg. When that section of Ohio was first settled, various symptoms of greasiness were detected, thin films of oil floating on the waters of Duck pond and its tributaries, globules rising in different springs, and seepings occurring frequently in the same manner as in Pennsylvania and West Virginia. Thirty miles north of Marietta, on Duck creek, a salt-well sunk by Mr. McKee, in 1814, to the depth of 475 feet, discharged 'periodically, at intervals of from two to four days and from three to six hours' duration, thirty to sixty gallons of petroleum at each inception.' Eighteen years afterwards the discharges were less frequent and the yield of oil dimin-

ished to one barrel a week, finally ceasing altogether. Once thirty or forty barrels stored in a cistern took fire from the gas at the well having been ignited by a workman carrying a light. The burning oil ran into the creek, blazed to the tops of the trees, and exhibited for hours to the amazed settlers the novelty of a rivulet on fire. Ten miles above McConnelsville, on the Muskingum river, results almost identical attended the boring of salt-wells in 1819. Dr. S. P. Hildreth, of Marietta, in an account of the region written that year, says of the borings for salt water:

" 'They have sunk two wells more than 400 feet; one of them affords a strong and pure water, but not in great quantity; the other discharges such vast quantities of petroleum, or as it is vulgarly called "Seneca Oil," and besides is subject to such tremendous explosions of gas, . . . that they make little or no salt. Nevertheless, the petroleum affords considerable profit and is beginning to be in demand for workshops and manufactories. It affords a clear, brisk light, when burned in this way, and will be a valuable article for lighting the street-lamps in the future cities of Ohio.'

"The last sentence bears the force of a prophecy. Writing about the year 1832 the same observant author directs attention to another peculiar feature:

" 'Since the first settlement of the regions west of the Appalachian range the hunters and pioneers have been acquainted with this oil. Rising in a hidden and mysterious manner from the bowels of the earth, it soon arrested their attention and acquired great value in the eyes of the simple sons of the forest. . . . From its success in rheumatism, burns, coughs, sprains, etc., it was justly entitled to its celebrity. . . . It is also well adapted to prevent friction in machinery, for, being free of gluten, so common to animal and vegetable oils, it preserves the parts to which it is applied for a long time in free motion; where a heavy vertical shaft runs in a socket it is preferable to all or any other articles. This oil rises in greater or less abundance in most of the salt-wells and, collecting where it rises, is removed from time to time with a ladle.'

"Is it not strange that, with the sources of supply thus pointed out in different counties and states and the useful applications of petroleum fairly understood, its real value should have remained unappreciated and unrecognized for more than thirty years, and be at last determined through experiments upon the distillation of bituminous shales and coals? Wells sunk hundreds of feet for salt water produced oil in abundance, yet it occurred to no one that, if bored expressly for petroleum, it could be found in paying quantity! Hamilton McClintock, owner of the 'oil-spring' famed in history and romance, when somebody ventured to suggest that he should dig into the rock a short distance, instead of skimming the petroleum with a

flannel cloth, retorted hotly: 'I 'm no blanked fool to dig a hole for the oil to get away through the bottom.' . . .

"Kentucky, the home of James Harrod and Daniel Boone, Henry Clay and George D. Prentice, was noted for other things besides backwoods fighters, statesmanship, sparkling journalism, thoroughbred horses, superb women and moonshine whisky. Off in the southeast corner of Wayne county, near the northeast corner of a 6000-acre tract of wild land, David Beatty bored a well for salt about the year 1818. The land extended four miles westward from the Big South Fork of the Cumberland river, its eastern boundary, and three miles down the Fork from Tennessee, its southern line. The well was located on a strip of flat ground between the stream and a rocky bluff, streaked with veins of coal and limestone. Five yards from the water a hole nine feet square was dug ten feet to the rock and timbered. The well, barely three inches in diameter, was punched 170 feet by manual labor, steam-engines not having penetrated the trackless forests of Wayne at that period. To the intense disgust of the workmen a black, sticky, viscid liquid persisted in coming up with the salt-water and a new location was chosen two miles farther down the creek. Extra care not to drill too deep averted an influx of the disagreeable fluid which spoiled the first venture. Salt-works were established and flourished for years, a simon-pure oasis in the interminable wilderness. . . .

"The abandoned well did not propose to be snuffed out unceremoniously or to enact the role of 'Leah the Forsaken.' In its bright lexicon the word 'fail' was not to be inserted merely because it was too fresh to participate in the salt trade. Far from retiring permanently, it spouted petroleum at a Nancy-Hanks quickstep, filling the pit, running into the Fork and covering mile after mile of the water with a top-dressing of oil. Somehow the floating mass caught fire and mammoth pyrotechnics ensued. The stream blazed and boiled and sizzled from the well to the Cumberland river, thirty-five miles northward, calcining rocks and licking up babbling brooks on its fiery march. Trees on its banks burned and blistered and charred to their deepest roots. Iron pans at the salt-wells got red hot, shriveled, warped, twisted, and joined the junk-pile. Was not that a sweet revenge for plucky No. 1, the well its owner 'had no use for' and devoutly wished at the bottom of the sea?"

Late in the '50's the real commercial importance of petroleum began to present itself to the minds of influential men in eastern United States. This was particularly true with reference to one George H. Bissell, who became so impressed with the idea that oil would be valuable commercially, if obtained in sufficient quantities, that largely through his endeavors a

company was formed and arrangements were made to sink a well on Oil creek, in Pennsylvania. It is reported that this idea was brought to his mind by examining a large label on a bottle of crude oil placed on the market for medicinal purposes in a drug-store window in New York city. The label, ingenuously devised and skilfully engraved, had on it pictures of derricks and tanks, with a statement that the oil was "discovered in boring for salt water near the banks of the Allegheny river." Mr. Bissell glanced at it and then in some way stopped to meditate. The inscription "400 feet deep" made an impression on his mind, and the thought flashed upon him, "Bore artesian wells for oil." The final outcome was that a company was formed and the now famous "Colonel" Edwin L. Drake was employed to go to Pennsylvania and take charge of operations. McLaurin describes matters as follows:

"Provided with a fund of $1000 as a starter, Drake was engaged at $1000 a year to begin operations. Early in May, 1858, he and his family arrived in Titusville and were quartered at the American Hotel, which boarded the colonel, Mrs. Drake, two children and a horse for six dollars and a half per week. Money was scarce, provisions were cheap, and the quiet village put on no extravagant airs. Not a pick or shovel was to be had in any store short of Meadville, whither Drake was obliged to send for these useful tools. Behold, then, 'the man who was to revolutionize the light of the world,' his mind full of a grand purpose and his pockets full of cash, snugly ensconced in the comfortable hostelry. Surely the curtain would soon rise and the drama of 'A Petroleum Hunt' proceed without further vexatious delays.

"Drake's first step was to repair and start up Angier's system of trenches, troughs and skimmers. By the end of June he had dug a shallow well on the island and was saving ten gallons of oil a day. He found it difficult to get a practical 'borer' to sink an artesian well. In August he shipped two barrels of oil to New Haven and bargained for a steam-engine to furnish power for drilling. The engine was not furnished as agreed; the 'borer' Doctor Brewer hired at Pittsburg had another contract and operations were suspended for the winter. In February, 1859, Drake went to Tarentum and engaged a driller to come in March. The driller failed to materialize and Drake drove to Tarentum in a sleigh to lasso another. F. N. Humes, who was cleaning out salt-wells for Peterson, informed him that the tools were made by William A. Smith, whom he might be able to secure for the job. Smith accepted the offer to manufacture tools and bore the well. Kim Hibbard, favorably known in Franklin, was despatched with his team, when the tools were completed, for Smith, his

two sons, and the outfit. On May 20 the men and tools were at the spot selected for the hole. . . .

"Delays and tribulations had not retreated from the field. In artesian boring it is necessary to drill in rock. Mrs. Glasse's old-time cook-book gained celebrity by starting a recipe for rabbit pie: 'First catch your hare.' The principle applies to artesian-drilling: 'First catch your rock.' The ordinary rule was to dig a pit or well-hole to the rock and crib it with timber. The Smiths dug a few feet, but the hole filled with water and caved in persistently. It was a fight to a finish between three men and what Stow of Girard—he was Barnum's hot-stuff advance agent—wittily termed 'the cussedness of inanimate things.' The latter won and a council of war was summoned, at which Drake recommended driving an iron tube through the clay and quicksand to the rock. This was effectual. Colonel Drake should have patented the process, which was his exclusive device and decidedly valuable. The pipe was driven thirty-six feet to hard-pan and the drill started on August 14. The workmen averaged three feet a day, resting at night and on Sundays. Indications of oil were met as the tools pierced the rock. Everybody figured that the well would be down to the Tarentum level in time to celebrate Christmas. The company, tired of repeated postponements, did not deluge Drake with money. Losing speculations and sickness had drained his own meager savings. R. D. Fletcher, the well-known Titusville merchant, and Peter Wilson, indorsed his paper for $600 to tide over the crisis. The tools pursued the downward road with the eagerness of a sinner headed for perdition, while expectation stood on tiptoe to watch the progress of events.

"On Saturday afternoon, August 28, 1859, the well had reached the depth of sixty-nine feet, in a coarse sand. Smith and his sons concluded to 'lay off' until Monday morning. As they were about to quit the drill dropped six inches into a crevice, such as was common in salt-wells. Nothing was thought of this circumstance; the tools were drawn out and all hands adjourned to Titusville. Mr. Smith went to the well on Sunday afternoon to see if it had moved away or been purloined during the night. Peering into the hole he saw fluid within eight or ten feet. A piece of tin spouting was lying outside. He plugged one end of the spout, let it down by a string and pulled it up. Muddy water? No! It was filled with *petroleum!* . . . That was the proudest hour in 'Uncle Billy' Smith's forty-seven years' pilgrimage. Not daring to leave the spot, he ran the spout again and again, each time bringing it to the surface full of oil. A straggler out for a stroll approached, heard the story, sniffed the oil and bore the tidings to the village. Darkness was setting in, but the Smith boys sprinted to the scene. When Colonel Drake came down, bright and early next morning, they and their father

were guarding three barrels of the precious liquid. The pumping apparatus was adjusted and by noon the well commenced producing at the rate of twenty barrels a day! The problem of the ages was solved, the agony ended and petroleum fairly launched upon its astonishing career.

"The news flew like a Dakota cyclone. Villagers and country folk flocked to the wonderful well. Smith wrote to Peterson, his former employer: 'Come quick; there 's oceans of oil!' Jonathan Watson jumped on a horse and galloped down the creek to lease the McClintock farm, where Nathanael Cary dipped oil and a timbered crib had been constructed. Henry Potter tied up the lands for miles along the stream, hoping to interest New York capital. William Barnsdall secured the farm north of the Willard. George H. Bissell, who had arranged to be posted by telegraph, bought all the Pennsylvania Rock-oil stock he could find and in four days was at the well. He leased farm after farm on Oil creek and the Alleghany river, regardless of surface indications or the admonition of meddling wiseacres. . . .

"Unluckily for himself, Colonel Drake took a narrow view of affairs. Complacently assuming that he had 'tapped the mine' —to quote his own phrase—and that paying territory would not be found outside the company's lease, he pumped the well serenely, told funny stories, and secured not one foot of ground! Had he possessed a particle of the prophetic instinct; had he grasped the magnitude of the issues at stake; had he appreciated the importance of petroleum as a commercial product; had he been able to 'see an inch beyond his nose,' he would have gone forth that August morning and become 'master of the oil country.' 'The world was all before him where to choose'; he was literally 'monarch of all he surveyed'; but he did n't move a peg! Money was not needed, the promise of one-eighth or one-quarter royalty satisfying the easy-going farmers, consequently he might have gathered in any quantity of land. Friends urged him to 'get into the game'; he rejected their counsel and never realized his mistake until other wells sent prices skyward and it was everlastingly too late for his short pole to knock the persimmons. Yet this is the man whom numerous writers have proclaimed 'the discoverer of petroleum'! Times without number it has been said and written and printed that he was 'the first man to advise boring for oil'; that 'his was the first mind to conceive the idea of penetrating the rock in search of a larger deposit of oil than was dreamed of by any one'; that 'he alone unlocked one of nature's vast storehouses,' and 'had visions of a revolution in light and lubrication.' Considering what Kier, Peterson, Bissell and Watson had done years before Drake ever saw—perhaps ever heard of—a drop of petroleum, the absurdity of these claims is 'so plain that he who runs may read.' Couple with this his incredible failure to secure lands after the well was drilled—

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wholly inexcusable if he supposed oil operations would ever be important—and the man who thinks Colonel Drake was 'the first man with a clear conception of the future of petroleum' could swallow the fish that swallowed Jonah!

"Above all else history should be truthful and 'hew to the line, let chips fall where they may.' Mindful that 'the agent is but the instrument of the principal,' why should Colonel Drake wear the laurels in this instance? Paid a salary to carry out Bissell's plan of boring an artesian well, he spent sixteen months getting the hole down seventy feet. For a man who 'had visions' and 'a clear conception' his movements were inexplicably slow. He encountered obstacles, but salt-wells had been drilled hundreds of feet without either a steam-engine or professional 'borer.' The credit of suggesting the driving pipe to overcome the quicksand is justly his due. The credit of suggesting the boring of the well belongs to George H. Bissell. The company hired Drake, Drake hired Smith, Smith did the work. . . . If the long-talked-of monument to commemorate the advent of the petroleum era ever be erected, it should bear in boldest capitals the names of Samuel M. Kier and George H. Bissell."

The foregoing somewhat lengthy quotations are justified because they deal with a critical period in the oil and gas industry of the world. We may now pass over all subsequent historical events very rapidly. From the inception of the industry on Oil creek in Pennsylvania, the field of operation spread northward into northern Pennsylvania, across the border line into New York, and thence into Canada, westward and northwestward into Ohio and Michigan, and ultimately into Indiana, and southward into West Virginia. The developments already mentioned in Kentucky increased until we now have considerable output from that state. Many states to the west beyond Kansas also are producers of considerable note. Oil is now being produced in Colorado, Utah, Wyoming; while the oil-fields of California surpassed those of any other state in the Union in productiveness very recently. Every one is familiar with the wonderful wells at Beaumont, Tex., and at points in Louisiana. How much of the remaining portions of Texas and the Gulf coast area in general is productive can only be surmised at the present time. For years oil has been obtained in sufficient quantity to support a small refinery at Corsicana. Recent operations beyond the Rio Grande, in Mexico, lead some to hope that there a field of great importance may be developed.

DEVELOPMENTS IN KANSAS.

The history of the discovery and development of oil and gas in Kansas may be divided into three parts: First, the earliest period, dealing with observations of surface indications and a little prospecting. Second, the period in which prospectors began using the drill actively. This preliminary drilling or prospecting seems to be a necessary and proper requisite to the development of any oil or gas region. Usually parties drill here and there wherever they happen to think indications are good; "wild-catting," as it is frequently called. Later, when more definite knowledge is obtained, more systematic development is possible. Third, the period of recent development, which begins about 1890 and continues to the present time.

First. It is said that the earliest settlers of eastern Kansas in the '50's learned from the Indians, and by direct observations, the locations of a number of oil-springs in several of the eastern counties. The Indian "medicine men" are supposed to have used oil in their "practice," while there are semilegendary tales of the great warriors holding their councils around the lights of burning springs.

How great or how little importance should be attached to these stories no one can say. But the numerous indications led many people to believe that here in eastern Kansas oil might be developed to an extent commensurate with the wonderful discoveries of Pennsylvania in the late '50's.

MIAMI COUNTY.—Encouragements were so great and the indications so favorable that, as early as 1860, Dr. G. W. Brown began prospecting for oil in Miami county east of Paola. But the political difficulties of 1861 put an end to his endeavors. His efforts in this direction, and causes which led up to them, are told so well in a letter recently received from him that the entire letter is here included:

"ROCKFORD, ILL., 907 KILBURN AVENUE,
October 28, 1903.

"*State Geologist of Kansas:* Yours of the 21st inst. received.

"In January of 1860 I visited Conneautville, Crawford county, Pennsylvania, where I established and published the *Courier* for seven years before going to Kansas. I found my old friends greatly excited on the oil question. Mr. Drake had opened the first oil-well at a depth of sixty-nine feet, if I remember correctly, in the eastern part of the county, and a well was commenced near Conneautville.

"I recall the fact that A. D. Searl, who originally surveyed

Lawrence in the spring of 1855, had detailed to me his discovery of an oil-spring on the Wea, in what is now Miami county, Kansas. So I hastened home and examined a file of the *Herald of Freedom* wherein the spring was described. Then getting Erastus Heath, then a member of the territorial legislature, which was in session in Lawrence, January, 1860, to join me, we visited the locality and found the spring described. The oil dripped from fissures in the rock and formed an oily surface on the rivulet which flowed at the base of the outcropping rock.

"We returned to Lawrence and organized a company of eight for purposes of exploration. This company, as organized, consisted of G. W. Brown, Erastus Heath, Maltravis Solomon, Doctor Barker, Seth Clover, W. R. Wagstaff and G. W. Miller. To this number was afterwards added Doctor Lykins. I was made president and business manager of the company. I visited the region and obtained leases on 30,000 acres of land for mining purposes to run thirty years. About June 1, 1860, two young men with boring apparatus commenced drilling a four-inch hole, and descended 100 feet. I kept a record of the rock through which we passed but it is mislaid or lost. I remember we passed through a stratum of coal of over two feet in thickness—I think at sixty-nine feet. I remember I made some estimate from the dip of the rock and estimated if continued the same at Leavenworth the stratum of coal would be there reached at 120 feet. I have never seen any account of coal being found in that region, so have no information as to the correctness of my figures.

"I found another spring of oil some eight miles south of that on the Wea, in the bed of a small stream. We started a second well there and continued it until near 100 feet, when we abandoned it temporarily, as the workmen had gone down the full length of their boring apparatus.

"Another well was started in an old well at the Baptist Mission in charge of David Lykins, about one mile east of Paola. I think we got down over a hundred feet below the bottom of the old well, which was blasted in the rock. This well we piped, cutting off with a seed-bag the water and oil entering the tube from all points above two or three feet from the extreme lower point. The pumping yielded salt-water, with a thin coating of oil, which formed on the vessels receiving it, showing that we were still in oil, as we had been most of the distance we had bored. We closed labor in all the wells in the winter of 1860-'61, with the intention of resuming borings in all of them in the spring. But the war coming on, we abandoned them temporarily. Before the war closed two members of the company died; two were in sympathy with the South and left the country, while others were almost financially ruined by the Quantrill raid on Lawrence in August of 1863; so work was never resumed.

"In the summer of 1860 I visited a point some sixteen miles south of our well on the Wea, and found in a ravine there a great mass of Maltha, the inspissated product of petroleum, formed during the ages. With great difficulty, because of its tenaciousness, we did succeed in chopping loose a small quantity to aid in starting a camp-fire. This was before the period of asphalt roads, or tar walks, hence we had no thought of utilizing it; but if still there and unappropriated there is doubtless a fortune for the owner.

"I saw somewhere recently what purported to be an account of the geological formations passed in the borings of the Lykins well near Paola; but it is far from truthful. I recollect giving to Professor Mudge a copy of my notes of the nature of the borings on the Wea, and I think I saw it afterwards quoted by Professor Swallow as furnished him, but I have no recollection of giving him anything.

"As a student of geology, I queried whether the main fountain from which the petroleum came in all the wells had not in the lapse of ages been carried away, and that was my real motive in tubing the Lykins well—to see and know for a certainty whether oil still came from the rock at the bottom of the well or dripped down from the earlier borings. The proof was conclusive that it came from beneath. It was our purpose to enlarge the size of the bore and to go down from 1000 to 2000 feet before abandoning the adventure; and this we should have done but for the unfortunate interruption when all adventure was unsafe.

"I have no history of the afterwards discovery of gas. Its finding should not deter a further penetration of the earth for oil, for the gas is usually found at a higher level than is the oil. My whole summer and autumn of 1860 was spent in studying the geological formation of eastern Kansas south of the river. Wife and I traveled in our own carriage, with our own horses, and whenever we could learn of outcropping rock by which the formations could be discovered we would camp and remain for days making our investigations. For four months we lodged in our carriage, and never slept in a house through the whole period. We carried my geological library with us, and gave our whole time to the subject. We were on our way to the Lake Superior region to continue our studies in the field when we came here in the spring of 1865 and were over-persuaded to buy property here, which permanently interrupted our trip and purpose.

"The notes of our observations in Kansas in 1860 were all mislaid or lost. Should you use any portion of this letter, oblige me with a copy of your report. . . .

Sincerely yours, G. W. BROWN."

Shortly after this a few wells were drilled in the vicinity of Mound City, producing small quantities of both oil and gas.

Soon after the close of the civil war public-spirited citizens of Paola took up the matter again, principally through the efforts of Hon. W. P. Wagstaff, W. T. Shively, and others, and employed Prof. G. C. Swallow, then state geologist for Kansas, to make a geological survey of Miami county, with special reference to the probability of finding oil. A short extract is here included:

"PETROLEUM.*

"The existence of 'tar springs' in Missouri and Kansas has long been known to the settlers and hunters of those regions, but they attracted no particular attention, as the 'rock tar' had been applied to no useful purposes, except as a lubricator of the freighter's wagon and a limited application as a domestic medical remedy.

"The late extensive application in the arts has caused careful explorations of these localities to be made, which have resulted in discovering a vast number of places where petroleum comes to the surface through the rocks and soils in greater or less abundance. Such, in fact, is the abundance of petroleum flowing from the springs in this county that no one can doubt that it comes from some abundant source.

"In our examination of Miami county, more than twenty places were observed where petroleum flowed from the rocks and soils in considerable abundance. The larger number of these springs are, as shown on the accompanying map, on the Wea, Middle creek, Marais des Cygnes and Sugar creek. There are numerous places in all parts of the county where the rocks are saturated with petroleum, or contain it in their cavities in the solid state, called asphaltum. There are also numerous wells in which petroleum was found in some of its varieties. In some it was so abundant as to entirely ruin the water, and the wells were filled up and abandoned.

"The most noted springs in the county are the Wea tar spring, the Beaver tar spring, the Won-zop-peah tar spring, Dale's oil spring, and Honeywell's oil spring.

"The Wea tar spring is on the Wea, in section 2, township 17, range 24, and flows from the partings and crevices of the sandstone No. 17 of our section above,* about fifteen feet below the overlying limestone. This spring doubtless discharges more petroleum than any other in the county, and has been known to the settlers and freighters for more than thirty years, and to the Indians from time immemorial.

"The Beaver creek tar spring is in section 8 of the same township, and springs from the same sandstone a few feet lower down, or thirty feet below the limestone No. 16.

"Dale's oil spring is in section 30, township 17, range 25, and

* Swallow, Prof. G. C., Kansas Geological Survey Report, 1866, pp. 85-89.

by no means confined to these three counties. Shawnee county, Bourbon county, and as far south as Cherokee county, little seeps of oil here and there excited the interest of observers. In the southwestern part of the latter county so much oil was found along a little creek that it gave rise to the name of "Tar creek," and the current belief was, and has been ever since, that if sufficient prospecting were done here, vast quantities of oil would be obtained.

The discovery of oil and gas in Kansas in paying quantities in recent times, therefore, is the natural and legitimate outcome of surface indications found here and there in so many places. It is a peculiar and interesting fact, however, that in every instance where valuable production has been obtained there have been practically no seeps of either oil or gas. These surface indications have been of great value by stimulating prospecting, but have, on the other hand, been very misleading, because they have excited interest and faith and hope where nothing of importance could be found. People are now learning that oil and gas held under pressure are trying to escape, and if they are escaping it is a sure indication they do not exist in the depths below under very considerable pressure, and hence not in very large quantities, because leakage long ago exhausted the great supply.

Second. The second part of our history may include the time period between 1870 and 1890. During this period a fair amount of drilling was done in many different places, principally by local companies and by drillers of limited experience, the locations for drilling being chosen almost entirely from the surface indications already described. Paola was looked upon as the center of the oil and gas territory. About seven miles to the northeast of Paola, in 1882, wells were put down, and a fair amount of gas was obtained and piped into the city. The drillers expected to find oil, for there were traces of oil on the water in springs and creeks. Encouraged by this fair success, drilling was prosecuted to a considerable extent throughout a semicircle reaching from northeast to southwest of the town. Occasionally an oil-well would be found producing a heavy, dark oil which found a ready local market at from three to five dollars per barrel for lubricating-oil. But a far greater value was found in the natural gas, which was obtained in sufficient abundance to supply the

city of Paola with lights and heat from those early days up to the present time.

The story of piping gas into Paola is so well told in a letter received from Judge B. F. Simpson, quoted, as he says, from Mr. H. M. McLachlin, that it is here included:

"In the year 1882, Jno. W. Werner, a hotel-keeper at Galveston, Tex., and who had come there from Pennsylvania, where he had been engaged in the oil business, was approached by H. J. Foote, a patent-right traveler, who stated that we had just as good indications of oil in the Indian Territory and Kansas as in Pennsylvania. They came up to the former place and found good indications, but could not get any leases, as the government controlled the land. Resuming their journey, they came to Paola, where there was an oil spring about eight miles east. This has been known to the Indians and settlers for years and had a local reputation as a 'cure-all' liniment. They examined the ground and it looked good, so they formed a company consisting of J. J. Werner, E. L. Mitchell, H. J. Foote, Chas. Kitchen, Jas. Briggs, A. Buck, E. M. Wickersham and H. M. McLachlin. Mr. Werner went east and purchased machinery, and, returning, commenced drilling on the Westfall farm in the vicinity of the oil spring. At a depth of about 300 feet, they struck a strong flow of gas, stopped the drill, and moved some distance, began drilling again, and had the same results—got no oil; then turning their attention to gas, they moved the machinery to Paola and drilled a well about 800 feet at the mill. Found two good coal deposits, but no gas. Then they moved the machinery east on Wea creek, and got some good wells, but were troubled so with water in them that they were finally abandoned. In 1884 a franchise for natural gas was procured from the city and the gas piped in. H. M. McLachlin sold out and B. Miller was elected in his stead, and it was under his management that the gas was brought in. Later on H. M. McLachlin purchased stock and was elected president and continued in that capacity until 1886, when the original stockholders sold out to the Kansas Oil and Mining Company. They tried for oil in the western gas-field and obtained it in good quantities, pumped quite a quantity, and erected a small refinery in the city and shipped a large lot of the oil out, but after spending $125,000 merged the company into the Franklin Fuel and Light Company, and abandoned the oil work."

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sandstones is so saturated with petroleum in places that it runs out into the soil or over the water, and fills the air with its peculiar odor; and where there are fractures or crevices the oil flows out in such abundance as to have acquired the name of 'oil' or 'tar' springs. Some of these localities are mentioned in the descriptions of those sandstones in the section above. There are other localities in these sandstones in this county and Linn, and in Bates and Cass counties, over the line in Missouri, but enough have been given to show the character and abundance of these manifestations of petroleum in this region.

"Nearly all the petroleum seen was of the dark, thick, heavy variety known in commerce as lubricating oil, which is much more valuable than the thin, amber-colored varieties.

"The thin, amber-colored variety, illuminating oil, was seen in places on the water in the branches, and particularly on the springs, which come up through the surface marls and soils; and the solid variety, asphaltum, was observed in numerous places in the cavities of the rocks and on the surface near the springs of the liquid varieties. Gas is more or less abundant at all the principal localities named.

"Such are some of the facts observed during the examination of Miami county, and it would seem they are sufficient to convince any one familiar with the indications and developments of petroleum in the productive oil regions of the country that it must exist in large quantities in this county. The facts that scarcely a well has been dug without finding petroleum in some of its forms; that four sandstones are in many places perfectly saturated with it; that more or less of it is found in the cavities of all the other rocks; and, above all, that it has been flowing in considerable quantities from some score of springs from time immemorial, are, to say the least, very strong evidence of the existence of large reservoirs near these localities."

Encouraged by such a flattering report, different companies were formed and a small amount of prospecting was done. But money was hard to raise, drilling was expensive, and at its best was mere child's play compared with the way oil-wells are drilled at the present time. Under such circumstances, partly from a lack, as it now seems, of a good supply of oil, and partly on account of a deficiency of funds and a want of experienced drillers, very indifferent success followed these undertakings.

WYANDOTTE COUNTY.—Wyandotte county came in for a share of interest, and a small number of wells were put down, some within the present city limits of Wyandotte. Here more gas was discovered than oil, although gas was almost unused anywhere in the world at that time. But "indications" were

by no means confined to these three counties. Shawnee county, Bourbon county, and as far south as Cherokee county, little seeps of oil here and there excited the interest of observers. In the southwestern part of the latter county so much oil was found along a little creek that it gave rise to the name of "Tar creek," and the current belief was, and has been ever since, that if sufficient prospecting were done here, vast quantities of oil would be obtained.

The discovery of oil and gas in Kansas in paying quantities in recent times, therefore, is the natural and legitimate outcome of surface indications found here and there in so many places. It is a peculiar and interesting fact, however, that in every instance where valuable production has been obtained there have been practically no seeps of either oil or gas. These surface indications have been of great value by stimulating prospecting, but have, on the other hand, been very misleading, because they have excited interest and faith and hope where nothing of importance could be found. People are now learning that oil and gas held under pressure are trying to escape, and if they are escaping it is a sure indication they do not exist in the depths below under very considerable pressure, and hence not in very large quantities, because leakage long ago exhausted the great supply.

Second. The second part of our history may include the time period between 1870 and 1890. During this period a fair amount of drilling was done in many different places, principally by local companies and by drillers of limited experience, the locations for drilling being chosen almost entirely from the surface indications already described. Paola was looked upon as the center of the oil and gas territory. About seven miles to the northeast of Paola, in 1882, wells were put down, and a fair amount of gas was obtained and piped into the city. The drillers expected to find oil, for there were traces of oil on the water in springs and creeks. Encouraged by this fair success, drilling was prosecuted to a considerable extent throughout a semicircle reaching from northeast to southwest of the town. Occasionally an oil-well would be found producing a heavy, dark oil which found a ready local market at from three to five dollars per barrel for lubricating-oil. But a far greater value was found in the natural gas, which was obtained in sufficient abundance to supply the

city of Paola with lights and heat from those early days up to the present time.

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sanatorium. Shortly after this a local company was formed, consisting of the following business men of Iola: Robert B. Stevenson, William H. McClure, W. A. Cowan, George A. Bowlus, H. L. Henderson, and others. The object of the company was to drill for gas. They were regularly incorporated under the laws of Kansas and obtained a charter from the city of Iola permitting them to pipe the city for the distribution of natural gas for public and private uses.

The first well this company drilled was located about 1000 feet southwest of the Acer's well. They struck the same gas-sand found in the Acer's well and stopped. The flow here was very moderate, so that it probably never paid for the cost of drilling. Their second venture was near the main wagon road leading west from Iola, about midway from the Atchison, Topeka & Santa Fe railway to the Neosho river. They found a little gas here at the same horizon and abandoned it. The third well was put down a short distance southwest of where the Lanyon zinc smelter now stands. At the proper depth they found the same gas-sand which produced the gas in the other two wells and reported that here it equaled about 600,000 cubic feet per day—probably too large an estimate. Not being satisfied, however, they carried the well still deeper and struck a strong flow of salt water, which destroyed the well. After this they drilled a fourth well, which likewise was located west of the Santa Fe railway track and produced nothing of commercial importance.

About this time they sold their entire interests, city franchises and all, to Messrs. Paullin & Pryor, and stipulated in the contract that the purchasers were to drill at least seven wells before they abandoned the field, even though all of them should be failures. The first well of the new company was located south of the present site of the Northrup lumber-yards, on the south side of Madison street and adjoining the Atchison, Topeka & Santa Fe right of way. This was a failure also. Well after well was drilled in the western part of the town until six out of the seven had been completed, with no one of the entire number producing enough gas to pay the first cost of drilling. This made an entire number of eleven wells which had been drilled with no success. The seventh well of the new company, however, was drilled further to the southeast, and at 840 feet they struck the gas-sand which has been so wonderfully productive in that territory. This

well was completed either in December, 1893, or January, 1894. Messrs. Paullin & Pryor now had an abundant supply of gas to meet all the demands of the young city. However, they drilled one more well, their eighth, which was about as good as their seventh.

Early in 1895 a new company was organized, known as the Iola Coöperative Gas Company. They located their first well in the southeast part of town, a few hundred feet away from the Paullin & Pryor well, and met with remarkable success, their well being one of the strongest ever drilled in the Iola field. At once they began to place gas from this well on the market. A lengthy litigation between the new company and the old ensued, which in February, 1898, resulted in the consolidation of the two companies with Messrs. Paullin & Pryor retiring soon afterwards, leaving the company substantially as it now is, the Iola Gas Company. During the next few years the Iola Gas Company drilled a few more wells, which met all their requirements.

Reports of the abundant supply of natural gas at Iola soon attracted manufacturing enterprises, such as brick plants, zinc smelters and Portland cement mills. Drilling was carried on extensively to the east, northeast and southeast, with a general result that one of the strongest gas-fields in the entire Midcontinental field was developed.

During the summer of 1904 a new gas-field was discovered lying to the north of the old field on each side of the Santa Fe track about half way between Iola and Carlyle. This is usually spoken of as the North field. A number of wells were obtained here as strong as the old wells in the old Iola field. The industrial interests at Iola in the form of zinc smelters, Portland cement plants, brick-yards, etc., had become so numerous that new gas territory was sought eagerly by them. As a result, a sharp competition sprang up in obtaining gas leases and prices the highest ever known in the state at that time were willingly paid, sometimes reaching an annual rental of over six dollars per acre throughout the life of the lease. The new field became pretty well defined within a year or so, as dry wells were found on practically all sides of it. Late in 1906 and early in 1907, still a third field was developed, lying to the west of the North field, which produced some of the largest wells ever found in the Iola district.

HUMBOLDT.—Guffey & Gailey were the first prospectors to

drill wells in the vicinity of Humboldt. In 1894-'95 they drilled a number of wells in this territory, no one of which proved very successful. One was in section 8, township 26 south, range 18 east, or about one and one-half miles southeast of Humboldt. A few others were drilled to the north of town. These wells either were dry or produced a small amount of heavy oil, so that they were not considered worth holding, and consequently the leases were abandoned later. In 1901, Mr. George Z. Work drilled a well on his land about 100 yards west of the Missouri, Kansas & Texas depot at Humboldt. This well produced about twenty-five barrels of oil per day. It was rather heavy, having a specific gravity of about thirty degrees Baume. Some years earlier, under the direction of the city school board, a well was put down in the corner of the schoolhouse grounds in the south part of town. It passed through an oil-sand of undetermined capacity and reached a supply of gas which was used for lighting and heating the school building. A few other wells were drilled, but no important development work was done until the recent development at Chanute, when prospectors again began drilling in the vicinity of Humboldt. This has continued with ever-increasing activity up to the present time. Drilling was first confined to the river valley west and south of town, but later it was extended to the uplands, particularly to the east, and soon reached the entire upland area to the east and southeast of Humboldt, particularly in township 26, range 18, and the western part of range 19. From here during the season of 1903 development spread southward on the uplands to opposite Chanute, making the upland development in two areas progress along parallel lines.

During the spring and summer of 1895 the Prairie Oil and Gas Company drilled a number of wells west of Humboldt which produced enough gas to have considerable commercial value. In August, 1897, it was piped into the city for general domestic use. The supply was not very large, however, until the rapid drilling for oil began, as above explained. About this time large quantities of gas were obtained, practically in all directions from town, so that at present Humboldt is well supplied with gas.

CHANUTE.—The history of oil and gas development in the vicinity of Chanute is an interesting and checkered one. In 1894, Guffey & Gailey put down one or two prospective wells, but, finding nothing, the territory was abandoned and a large

acreage of leases given up. Later the Prairie Oil and Gas Company obtained a strong gas-well about sixteen miles to the west and laid pipes into Chanute to supply the city with gas. This, in connection with discoveries made elsewhere in the state, stimulated the citizens of Chanute to continue their investigations. The city took up the matter and drilled a few wells in the Neosho valley to the east of town. They met with fair success, each well passing through an oil-sand at about 730 feet. After passing through forty feet of shale, the drill reached a gas-sand which yielded gas at the rate of from one million to three or four million cubic feet per day. Drilling was continued by the city until a satisfactory supply of gas was obtained for lighting and heating. It is interesting to note that this is the only city in the entire oil- and gas-fields of the state which owns its gas supply. It has made very low rates, as shown later, and yet derives sufficient income to make many municipal improvements.

While investigating the Kansas oil-fields in 1899, Mr. I. N. Knapp had his attention called to the showing of oil in these city gas-wells. He considered the showing sufficiently favorable to warrant him in prospecting for oil. Accordingly he obtained leases over quite a wide area and began prospecting both east and west of the city of Chanute. It was but a short time until he had a number of fair oil-wells in the valley east of town and in June, 1900, he began shipping oil to Omaha and Kansas City gas companies where he obtained contracts. This was really the beginning of the oil development in the vicinity of Chanute.

Mr. Knapp was followed by a company composed principally of local business men and citizens of Iola, who organized the Neosho Valley Development Company, obtained leases, and began drilling. They had fair success from the start and soon had a number of producing wells. They were soon followed by a company composed principally of Kansas City business men, who organized the Southwestern Development Company, which likewise secured leases in the river valley and met with fair success in obtaining oil. From this time on the development was rapid. At the end of a year there were derricks and pipe-lines all along the valley to the east and north of Chanute, and half way to Humboldt. In the midsummer of 1902, the Prairie Oil and Gas Company built a large storage-tank at Chanute with a capacity of almost 40,000 barrels. This was

followed by a pipe-line between Thayer and Chanute which, joined to the Neodesha-Thayer pipe-line, gave Chanute a direct pipe-line connection with the Standard refinery at Neodesha. A pump was established and the first oil turned into the line about the middle of December, 1902. The Prairie Oil and Gas Company at this time began extending its lines to oil-tanks here and there all through the field. By July, 1903, they had reached as far north as Humboldt and had been carried eastward to the upland developments to the east of Humboldt and northeast of Chanute. During the calendar year 1902 the Chanute territory produced over 165,000 barrels of oil, and could have marketed much more if there had been pipe-line connections. In the first half of 1903 the production was raised from 50,000 to 75,000 barrels per month, with the number of wells constantly increasing.

Development gradually migrated southward down the river with only moderate success in the vicinity of Austin and a few fair oilers in the vicinity of Shaw. Still further south a few good wells had been obtained near Urbana and Earleton and in the territory lying to the northeast of Thayer, in the extreme southwest corner of the Iola quadrangle. Gas development likewise extended rapidly in different directions, but particularly to the east and west, making Chanute a great center for gas as well as for oil.

During the latter part of 1906 and all of 1907 a renewed activity in well-drilling sprung up in the narrow rich gas territory to the southwest of Chanute, in the vicinity of Vilas, where years before Col. F. E. Isett organized the Isett-Erwin Oil and Gas Company and took leases in the vicinity of Vilas. He obtained one phenomenal well with a capacity of about twenty million cubic feet per day. But gas was not greatly in demand in those times and his attempt to secure oil proved a failure, so that the company finally was disbanded. By 1906 gas had become a very desirable product commercially and new developments in the vicinity of Vilas were based largely on the success of Colonel Isett years before. By the end of 1907 a large number of wells had been drilled and almost all of them were good gas-wells, some reported to reach a capacity of thirty million cubic feet per day.

ERIE.—Prospecting began in the vicinity of Erie about 1900, but was carried on in a somewhat desultory way until 1902. About this time a company was organized under the name of

the Erie Gas and Mineral Company. In August, 1903, they reported that a total of thirty-five wells had been drilled by their company, fourteen of which were gas-wells, seven oil-wells, and fourteen dry. The gas was piped into the city and supplied practically the entire population. During the summer of 1903 some prospecting was done in the river valley between Shaw and Erie, which in some cases gave very satisfactory results, but up to the date above mentioned, nowhere to the southeast of Chanute had oil or gas been found in quantity or volume at all comparable with that in the Chanute and Humboldt fields.

INDEPENDENCE.—The history of the development at Independence is so well told in a letter received from Hon. W. T. Yoe that it will be copied entire. Under date of April 9, 1905, he wrote as follows:

"Looking backward to the beginning of the natural gas and oil development in Montgomery county, and especially around Independence, Kan., we are impressed with the benefit of the speculator and the conservatism of capital. In the early '70's, coal in thin veins was found near town in several localities, and two companies organized to develop veins, but all proved failures. In 1884, Dr. B. F. Masterson, of this city, with others, raised a fund to drill for coal, and located it on lot 6, block 17. The work was expensive and money difficult to obtain, and when the drill had reached 1200 feet one night the gas spouted the oil and water out, and as the oil ran past the boiler it ignited and burned all the lumber about the place. No one then thought that they had struck natural gas and oil, and as coal had been discovered in quantity, it became impossible to raise money to continue prospecting. Two years later, in '86, a franchise was granted for a gas plant, the rates to be $2.50 per 1000 feet for manufactured gas, and street lights $33 per year, but the promotors were unable to obtain the required number of customers. The following year the talk of natural gas at Paola and Fort Scott had reached Independence and a gas company solicited $5000 in capital stock, but found few takers. During the following year there were revivals of natural gas agitation, but not until 1892-'93, after gas had been found at other near-by towns in limited quantities did gas development take form. In the spring of 1892, William H. Barnes, now secretary of the State Horticultural Society, then a gardener in our city, had his faith worked up and organized the Ætna Gas Company, which sold stock and accepted donations 'to drill 600 feet, or, if necessary, to the vein which blew the drill out of the coal-hole well,' to find natural gas. Mr. Nickerson, a well-driller from Miami county, was employed to drill, and, in September struck a small flow

of gas at 600 feet, and at lower depths found two other flows of gas, but only enough for two stoves and the Barnes greenhouses. The Ætna company raised more money and had a well drilled on the Captain Mason farm east of town, near the Verdigris river, but was not able to find gas, and further operations were abandoned for lack of nerve and cash.

"A Profitable Find.

"The driller, Mr. Nickerson, was satisfied there was gas in this vicinity, and on going back to Miami county interested A. P. McBride and C. L. Bloom, both drillers, and in 1893 they leased lands four miles east, in the Overfield school district, and were so well satisfied that they got a franchise to pipe gas into the city and a pledge of a donation of $1000 when they delivered gas. During the spring months they drilled their first well on the Brewster Park farm and at about the thousand-foot level found both gas and oil, but it was not a strong well. The gas was piped off about thirty feet and ignited and the burning was a great event. Other wells and better ones were drilled on that farm, and two drills were put to work and two wells drilled on the G. W. Waggener farm adjoining, and gas found at about 600 feet. In the meantime, McBride, the enthusiast, gave out most hopeful encouragement, boasted of ample supply, and startled the natives when he declared the company would expend $30,000. By July there were six wells, not strong ones, but sufficient, and a pipeline was started to Independence. Mr. Brewster was enthusiastic and one night in July the public was invited to his home and great crowds drove out to see the "seven wonders." The gas had been piped off to near the road, and for half a mile there was natural gas illumination and from stand-pipes sixteen feet high burned flaming torches and all about his home there was a fine display. To the majority, who had never seen natural gas, it was the sight of a lifetime, and addresses were made by a number and Independence's future was assured.

"Gas in Town.

"In November the gas was piped to Independence and the business houses and some residences plumbed for gas and a pipe run to above the flagstaff on the court-house, and during the early days of the month the gas was turned on. Independence was at its glory and all felt that its industrial future was made, and from that time to this, barring a few hours of time for breaks at different times, twice in the coldest weather, our city has had gas for all purposes.

"Although gas had been found and was utilized for all manufacturing, heating and lighting purposes, the people did not realize its vast importance, and for several years the Independence Gas Company had the field alone. The first wells were becoming exhausted and the field was being prospected

with varying results, finding wells producing from three to six million cubic feet daily capacity in various parts, when in 1902 the Independence Gas Company 'wildcatted' to hold some leases in the Bolton neighborhood, and this first venture resulted in finding a fourteen-million-cubic-feet gasser; and in succession they drilled six others, producing from ten to fifteen million cubic feet daily. Their seventh drilling in that field produced a forty-barrel oil-well, and that gave the impetus for developing the greatest oil-field in Kansas and the spending of a million dollars in that industry, some of the wells showing a flow of 1000 barrels of oil the first day. The years following, 1903-'04, the oil prospecting east of that field and south of Independence developed another great gas-field, wells producing from twelve million to one of thirty-seven million cubic feet of dry gas daily—in the aggregate, hundreds of millions daily. The Independence field now has on tap 700 million cubic feet of gas, and from it is projected a sixteen-inch main to furnish gas for lighting purposes to all the cities within 150 miles, while at home the Kansas Natural Gas Company is advertising to furnish factories with gas at three cents per 1000 feet and the supply is deemed sufficient for half a century. W. T. YOE."

While Independence has been noted more as a gas territory than as an oil territory, it should be stated prominently that the richest oil-field ever yet opened up in Kansas lies only a few miles to the west and southwest of Independence. Large gas-wells had been obtained previous to 1903 in the gas territory to the south of the little town of Bolton, the first station southwest of Independence on the Bartlesville line of the Atchison, Topeka & Santa Fe railway. Late in 1902 oil developments began just north of the gas territory and wells with a capacity of a thousand barrels a day were obtained, so that in about two years the Bolton district was the most noted oil district in the state. Hon. G. L. Banks, of Independence, is the fortunate landowner of some of the best land in the field. Regarding the development in the Bolton field, he wrote, under date of April 14, 1905, as follows:

"The first well in the Bolton field was drilled by McBride & Bloom in the fall and winter of 1902 and 1903 on the southeast quarter of the southeast quarter of section 18, township 33, range 15 east, on land owned by Jeff Bolt. It was commenced in October and completed in the following February. McBride & Bloom were the principal stockholders in the Independence company, and were drilling for gas when they struck oil. The depth of well was 1180 feet; the thickness of oil-sand about 15 feet; output of well about forty barrels per day.

"The next well drilled in was on the southwest quarter of the southwest quarter of section 17, about 500 feet east of the Bolt well, on land owned by J. D. Atkinson. This was a better well than the Bolt well. It was reported as making ninety barrels per day.

"The next was a dry hole drilled in June, 1903, by Reese & Hazlett on the northeast quarter of section 17, on land owned by E. Earhart. The next well was drilled on the northeast quarter of the southwest quarter of section 8, township 33, range 15, owned by G. L. Banks. It was brought in on July 3, 1903, and reported as a seventy-five-barrel well. The next producing well was drilled in October, 1903, on the northeast quarter of the southeast quarter of section 17, by the New York Oil and Gas Company, on land owned by a Jew by the name of Schoenburg, and was a fairly good oiler, and also was quite a strong gasser. There were several wells started about this time around this forty-acre tract. The depth of all the wells drilled so far varied from 1150 to 1200 feet. Oil-sand in Atkinson well was about 15 feet, in Banks well about 10 feet, and in Schoenburg well about 28 feet.

"The next well brought in was drilled by Kennedy & Son for Rider & Miller on the northwest quarter of the southeast quarter of section 17, on land owned by G. L. Banks, and was reported as making 1000 barrels per day. It was shot on the 22d day of October, 1903, and filled a 250-barrel tank in five hours. In this well a stratum of oil-sand was found at a depth of 1016 feet, 15 feet thick and very rich in oil. At a depth of 1156 feet another stratum of oil-sand was found, about 30 feet thick. It was while the oil was flowing from both these strata of oil-sand that it was reported as making 1000 barrels a day, which it possibly made for the first day or two. They were not able to case the well for three days, and then were obliged to case off the upper stratum of oil-sand. Its daily output for about six months after it was cased was 235 barrels per day. It is now making about 40 barrels per day.

"I have no means of knowing exactly how many producing wells there are in the Bolton field at this date, but there are about 200.

"The Standard finished its pipe-line from Neodesha to the Bolton field the first week in September, 1903. They commenced buying oil as soon as the line was completed. Their records show that the first oil was received from the Atkinson well September 13, 1903; the Banks and Schoenburg wells, October 23, 1903. The above dates were obtained from the Prairie Oil Company's office, so doubtless they are correct.

"While this may not cover all the points that you want, it is the correct history of the development in this field as far as I am able to get it from the records and men who did the work.

G. L. BANKS."

COFFEYVILLE.—The first development in oil and gas in the vicinity of Coffeyville was made under the direction of Mr. W. P. Brown, a leading merchant of that city. Mr. Brown had become convinced that gas or oil might be obtained in commercial quantities by proper search. The result was that in the autumn of 1892 pipes were laid in the streets of the city for supplying private buildings with light and fuel.

Coffeyville, the same as most other towns, has had quite a varied experience in the way of changing companies, attempted monopolies of supply, and other matters of a business nature, but through all of this she has had a good supply of gas, obtained partly from under the city itself and partly from wells to the east, but principally from the large gas-wells obtained from three to eight and ten miles west and northwest. The Coffeyville field connects with the field at Deering and from that by way of Jefferson to the big gas-field south of Independence, practically without any barrier. No town in the state has been better supplied with gas and no town has had a more active and energetic set of citizens, who have brought in factories of various kinds to consume the gas at home. Coffeyville seems to have made a specialty of glass plants, so that at the present time it is by far the greatest center for manufacturing almost all kinds of glassware, excepting plate glass, west of Pittsburg; all on account of her great abundance of gas for fuel and the extraordinary push and energy of her citizens.

Coffeyville has never been noted as an oil center, yet in 1902 and 1903 a very considerable amount of oil was obtained northeast and southwest of town.

CHERRYVALE.—The history of obtaining gas at Cherryvale is similar to that in a number of other towns in the state. The first few attempts resulted in failures, but perseverance finally produced excellent results. Mr. Butler, secretary of the Cherryvale Gas Company, once said to the writer that when he first began prospecting about Cherryvale he found so many dry wells that he just simply could not quit, because everything he had in the world was invested in holdings in this town. Fortunately for him and the world he obtained a good gas-well before funds entirely gave out. Gas-pipes were laid in the streets of Cherryvale in 1893, since which time the town has had an abundance of gas for every purpose. The Cherryvale Gas Company, under the efficient management of its secretary,

J. H. Butler, has developed a good production principally to the east of the town. In 1898 the Edgar Zinc Company established its mammoth smelters at Cherryvale, after having obtained a satisfactory supply of gas, principally from the field a few miles to the north. Other interests of lesser importance have been attracted to Cherryvale, but aside from the smelter and one or two small glass factories the only manufacturing interests of note are brick plants. Cherryvale supports a total of six brick plants, each of which is now doing a prosperous business on a large scale. The town is largely surrounded by hills and mountains composed almost entirely of shale very suitable for making high-grade brick of many varieties. This combination of gas and good material has resulted in making Cherryvale the greatest brick producing center in the entire gas district of the state.

CHAUTAUQUA COUNTY.—A small amount of drilling was done in Chautauqua county in 1894-'95, principally in the vicinity of Niotaze and Peru. Guffey & Gailey drilled a few wells and Mr. Gyser a few more, from one or two of which he obtained a small supply of gas that was piped into the village of Peru. After the interests of Guffey & Gailey passed to the Forest Oil Company, the leases were allowed to lapse, but Mr. Gyser kept his leases alive, which later proved the making of a snug fortune for him. Early in the spring of 1903 a new impetus was given to the Chautauqua county fields. The first large company to begin developments was the Chautauqua Oil and Gas Company, which obtained leases aggregating almost 8000 acres. Partly by their own development and partly by subleasing they soon had a good supply of oil ready for the market. Simultaneous with their development other companies began operations and a rich oil-field was soon developed from five to seven miles south of Peru, known as the Blundell-Spurlock field. A year later extensive developments were made in the Huffman field, six miles west of Peru and three miles south of Sedan. About the same time a nice oil-field was opened up two miles north of Peru, known as the Alford field. Practically simultaneously with all this also, Mr. Gyser obtained a considerable number of good wells in the valley land just east of Peru, and drilling was carried into the village itself, with the result that probably more than half of the town lots in the little village had derricks erected and wells drilled. A nice pool of oil was found immediately under the town, so

that every well in town was practically sure to find oil. So many wells were drilled, however, that the supply of oil lasted only about two years, after which very largely the casings were drawn and the wells abandoned. Chautauqua county, in the aggregate, probably has produced more oil than any other county in the state, although exact statistics are not at hand. The oil of this county uniformly is of a high grade compared with other parts of the state, all of it bringing the highest price in the market. Throughout the entire field gas-wells are here and there found, so that Chautauqua county is well supplied with gas. It is interesting to note, however, that thus far no especially strong gas-wells have been obtained, nor has there been developed an especially strong gas territory. Wells ranging from one million to four million cubic feet daily capacity seem to be the rule. The latest development in this line is the new territory in the northeast part of the county in the vicinty of Hale. Here a group of wells has been drilled during the last two years, almost every one of which is a good gas-well, with a capacity ranging from two and one-half to four million cubic feet per day. It looks as though a gas territory of considerable note will soon be developed there.

Every one is greatly interested in the question of the westward limit of the oil- and gas-fields. "Wildcatting" has been done in a number of places, which has resulted in obtaining a number of fair gas-wells in three or four places on the west outside the main fields. Such is the case at Longton, Elk Falls, Moline, Dexter, Winfield, Arkansas City, Augusta and Elmdale, each of which has a fair supply of gas that apparently is capable of further expansion by more drilling.

CHAPTER II.

HISTORY OF FIELD-WORK.

By ERASMUS HAWORTH and JOHN BENNETT.

BEFORE beginning a discussion of the stratigraphy of the Kansas fields, a short sketch of the work done by others may be of interest. The geological investigations made in eastern Kansas by different geologists may be divided chronologically into three groups: First, covering a time period from earliest investigations down to about 1875; second, from this date to the organization of the University Geological Survey of Kansas in 1894; and third, from 1894 to the present time.

During the first period the principal workers were Messrs. F. B. Meek and F. V. Hayden, who worked and published together, Maj. F. Hawn, Prof. J. S. Newberry, Prof. G. C. Swallow and Prof G. C. Broadhead, to which list might be added Dr. G. G. Shumard and Capt. R. B. Marcey, who did work in adjoining areas that has a bearing on Kansas geology.

During the second period work was done by Prof B. F. Mudge, O. H. St. John and Robt. Hay, with an occasional paper on some special subject by various specialists in their particular branches of science, such as Dr. F. H. Snow, Prof. G. E. Patrick, Mr. Joseph Savage and Prof. S. W. Williston, and a number of others whose papers were published principally in the Transactions of the Kansas Academy of Science and in current scientific magazines.

During the third period work has been done continuously and uninterruptedly by the University Geological Survey of Kansas under its present management and, to a lesser extent, by the United States Geological Survey, generally having a semicoöperation arrangement with the State Survey.

First Period.—From 1852 to 1860 Capt. R. B. Marcey and Dr. G. G. Shumard made explorations along the Red river, in Louisiana, the Pecos and Rio Grande, in Texas and New Mex-

ico, and other places in the Southwest, and obtained results which have an indirect bearing on Kansas geology. It seems they did not actually enter the state of Kansas and therefore can hardly be included in the list of Kansas geologists.

Maj. F. Hawn was located at Fort Leavenworth, being attached to the United States army. He spent a considerable portion of his time in a study of the geology of eastern Kansas and adjacent areas, played an important part in the recognition of Permian fossils in Kansas, which established the fact that Permian rocks occur in the Mississippi valley, did a great work in the discovery of coal at Leavenworth, and, in fact, organized the first company and superintended the sinking of the first shaft which discovered coal, and in other ways added greatly to our knowledge of Kansas geology in early times. He published principally in the Reports of Missouri State Geological Survey, Transactions St. Louis Academy of Science, Geological Survey Report of Kansas under Professor Swallow, and in different governmental reports. In the preface to his report as state geologist, published in 1866, Prof. G. C. Swallow speaks of Major Hawn as follows: "Maj. F. Hawn has given the Survey the full benefit of his intimate and extensive knowledge of the state and its resources, and the collections made during his previous explorations, in connection with the lineal surveys of the general government. His reports are full of scientific and practical information."

Prof. F. B. Meek was a veteran of early-day geological work in many parts of the Mississippi valley. He worked and published principally with Dr. F. V. Hayden, who was at the head of the United States Geological and Geographical Survey of the Territories. Professor Meek made a number of excursions through Kansas, the most notable being the one made with Dr. F. V. Hayden. Their own description of the route traveled is as follows:[1]

"The route pursued by us while making these investigations was first from Leavenworth city, on the Missouri, across the country to Indianola, near the mouth of Soldier creek, on the Kansas; thence up the north side of Kansas and Smoky Hill rivers to the mouth of Solomon's Fork. Here we crossed the Smoky Hill, and followed it up on the south side to a point near the ninety-eighth degree of west longitude, from which point we struck across the country in a southeast direction to the Santa Fe road, which we followed northeastward to the head

1. Proc. Acad. Nat. Sci., Philadelphia, 1859, p. 8.

of Cottonwood creek. Leaving the road here, we went down the Cottonwood valley some thirty miles, when we turned across the country nearly due northward to Council Grove. From the latter place we followed the Santa Fe road back southwestward about twenty-four miles to a watering-place known as 'Lost Spring'; here we again left the road and struck across the country in a northwest direction to Smoky Hill river, at a point nearly opposite the mouth of Solomon's Fork. We then traveled down the south side of Smoky Hill and Kansas rivers to Lawrence, where we crossed the Kansas and proceeded in a northeast direction back to Leavenworth City."

Professor Meek also did considerable work on both sides the Missouri river from Leavenworth to Omaha, and published results of his investigations in the Final Report of the United States Geological Survey of Nebraska and Portions of Adjacent Territories, published in Washington in 1872. Particular reference should be made to the article by Meek beginning on page 83 of this report. In all of their work in Kansas Meek and Hayden did but little in the way of suggesting detailed geological names to individual formations, and contented themselves with the use of numerals for such designations. They performed an important part, however, in recognizing the great divisions in Kansas, such as the Carboniferous, Permian, Cretaceous, etc.

Prof. G. C. Swallow, although located in Missouri, made a great impression on early Kansas geological literature. In a degree he was associated with Major Hawn in the recognition of the Permian in Kansas. One writer, in discussing this subject, wrote as follows:[2]

"The early geologists of the state, Hawn, Swallow, Meek and Hayden, engaged in a spirited controversy, not only in regard to the correlation of the geological formations of this part of the state, but also as to whom belonged the honor of announcing the discovery of the Permian rocks in Kansas. Major Hawn stated that his first impression that the rocks in question might be of Permian age was obtained from a letter written by Mr. Meek September 3, 1857. (Am. Jour. Sci., 2d series, vol. XXVI, p. 188; ibid, vol. XLIV, p. 38; Trans. Acad. Sci. St. Louis, vol. II, p. 511.) On January 19, 1858, at the request of Meek and Hayden, a record was made at the Smithsonian Institution in which is mentioned 'forms indicating Permian both in Kansas and the region of the Black Hills.' (Am. Jour. Sci., 2d series, vol. XLIV, 1867, pp. 38, 39; see ibid, vol. XXVI, 1858, p. 188, and Trans. Acad. Sci. St. Louis,

2. Prosser, Prof. Chas. S. Classification of the Upper Paleozoic Rocks of Central Kansas. Journal of Geology, vol. III, p. 683, Chicago, November, 1895.

vol. II, p. 511.) In determining the date of the first scientific publication of the discovery of Permian fossils in Kansas neither of these records should be considered. The first public announcement before a scientific society of the identification of Permian fossils in Kansas was made by Prof. G. C. Swallow in a letter read by Prof. B. F. Shumard before the St. Louis Academy of Science on February 22, 1858. (See Trans. Acad. Sci. St. Louis, vol. I, pp. 111, 112.) The letter, which was dated February 18, contains the identification of several species collected by Major Hawn. Professor Swallow states: 'I can have no doubt that the rocks are Permian, since the proof is very conclusive to my mind. . . . All the described fossils, with perhaps two exceptions, are identical with Permian species of Russia and England, while all the new species appear to be more nearly allied to Permian forms than to any other.' At the same meeting a portion of a paper by Professor Swallow and Major Hawn was read, entitled 'The Rocks of Kansas, with Descriptions of New Fossils from the Permian Formation in Kansas Territory.' The reading of this paper was concluded at the following meeting, on March 8. (Trans. Acad. Sci. St. Louis, vol. I, pp. 112, 113, and pp. 173-197.) An abstract of the paper was read at the Baltimore meeting of the American Association for the Advancement of Science, May, 1858, and appeared in the *American Journal of Science* November, 1858 (2d series, vol. XXVI, pp. 182-188); also published in Proceedings of American Association for the Advancement of Science, vol. XII, 1859, pp. 214-221, where Professor Swallow says: 'The Coal Measures occupy a belt along the eastern end of the territory, extending westward as far as Fort Riley. West of the Coal Measures the Permian strata are developed over a wide zone, stretching across the territory from north to south' (p. 220).

"Apparently the first published announcement of the Permian age of the Kansas fossils was a letter from Prof. G. C. Swallow to Prof. J. D. Dana, dated February 16, 1858, and printed in the March number of the *American Journal of Science and Arts* (2d series, vol. XXV, p. 305). Swallow mentioned some ten European Permian species; these or closely allied species he had identified in Major Hawn's collection, and he stated, 'I can but feel that the above is sufficient to justify us in the decision that they are Permian.'

"On March 2 Prof. James Hall read a paper by Meek and Hayden before the Albany Institute, describing a small collection of fossils 'from near the mouth of the Smoky Hill fork of the Kansas river,' concerning which is the statement: 'We think there is scarcely room to doubt that it [the formation] is of Permian age.' (Trans. Albany Inst., vol. IV, p. 76.) The paper is entitled 'Descriptions of New Organic Remains from Northeastern Kansas Indicating the Existence of Permian Rocks in that Territory' (pp. 73-89). This paper was noticed

in the May number of the *American Journal of Science* (2d series, vol. XXV, p. 442). A letter from Meek and Hayden, making brief mention of the discovery, was read the same day before the Philadelphia Academy of Natural Sciences (Proc. Acad. Nat. Sci. Philadelphia, vol. X, pp. 9, 10).

"After reviewing the various statements referring to the discovery of Permian rocks and fossils in Kansas, it appears that to Professor Swallow belongs the credit of first announcing the fact before a scientific society and publishing a notice of the discovery in the leading scientific periodical of the country. Professor Hayden stated that extras of the Albany Institute paper were distributed two days after it was read, so that the paper 'was actually published on the 4th of March,' but he seems to have been in error in stating that the March number of the *American Journal of Science,* which contained Professor Swallow's letter, was issued 'between the 4th and 10th of March' (Am. Jour. Sci., 2d series, vol. XLIV, 1867, p. 38, d. n.) The Proceedings of the Albany Institute for March 2, 1858, following the remarks of Professor Hall upon Mr. Meek's paper, contain the following statement: 'Mr. Gavit called attention to the fact that, in the last number of *Silliman's Journal,* Professor Swallow makes a similar announcement as to the identity of certain fossils of Nebraska with those recognized as Permian.' (Trans. Albany Inst., vol. IV, p. 248.) Finally, Prof. James D. Dana wrote me: 'I have no doubt that the number for March, 1858, was out and off by the 1st [of March] if not before.' (Letter of March 28, 1895.)"

Professor Swallow did his greatest work in Kansas while serving as state geologist. His report was published by the state under date of January, 1866. This report includes a "Section of the Rocks in Eastern Kansas." Beginning with the Cretaceous and numbering downward the numbers extend from 1 to 256, inclusive, and in a way cover everything from the Cretaceous down to and including the Lower Carboniferous. When we consider the youthfulness of the science of geology at that time in connection with the limited means for exploration available for Professor Swallow and his colaborers, it is surprising how accurately they grasped the true geological conditions of Kansas. The boundaries between the great geological divisions were located by them with a high degree of accuracy. They recognized surprisingly well the extent and value of the Coal Measures of eastern Kansas and the salt and gypsum deposits in the middle part of the state.

But when we come to a detailed study of the individual beds of limestone, sandstone and shale we find that Swallow was led into error many times in his correlations. This fact is

pointed out here, not with a spirit of criticism, but because it should be known in order to set ourselves right for the system of nomenclature adopted later in this volume. For example, on page 47, Swallow speaks of the "Well Rock" as outcropping on Sugar creek in Anderson county, where it is forty-eight feet thick. He then describes it as being in the ford of the Marais des Cygnes on the "Telegraph road," where it is eight feet thick. "Thence it may be traced from stream to stream and slope to slope till found near high-water mark at Lecompton and on the tops of the ridges at Lawrence. This last position it holds in the ridge to Leavenworth, where it is bluish-gray and brown and subcrystalline. Thence it continues cutting ridge and valley to Wolfe river and to the northern border of the state."

By turning to his system of classification, page 20, it is found that he places the Well Rock series first below the Spring Rock series, that below the Cave Rock series, and that in turn below the Stanton limestone series, making an aggregate, according to his figures, of 237 feet below the top of the Stanton limestone series.

We now know that he confounded the Oread limestone, which occurs at Lecompton, Lawrence, Leavenworth, etc., with this Well Rock series. The Oread is fully 300 feet above the Stanton rock of Swallow along the Marais des Cygnes, which, added to the 237 feet just mentioned, makes an error of fully 537 feet in this connection.

On page 20 his number 156 is called Cave limestone, and is given as occurring at Beaver, Sugar creek, and at Topeka. The limestone at Topeka here referred to is fully 700 feet above the limestone he refers to along Sugar creek, and to go from one to the other one must cross over not only the Oread limestone, the Lawrence shales and the Stanton limestone, but all of the limestones and shales lying between the Oread and the Topeka limestones. On page 21 Swallow mentions the Spring Rock series, which he numbers from 158 to 168, inclusive. Number 162 of this series he labels Spring Rock and gives for its locality Beaver creek, Marais des Cygnes, Johnson's coal-bed west of Topeka, and Lecompton. Here again he covers a vertical distance of fully 700 feet, and crosses about as many different formations as he does with the Cave Rock series. He has thus intertwined the various strata of his Cave Rock, Spring Rock, and Well Rock series much as

we intertwine the strands of a three-ply braid. In a similar manner his Well Rock series, numbered 167 to 177, inclusive, is made to cover an area from as low as the Marais des Cygnes, in Miami county, to as high a position as the Oread in the vicinity of Lawrence, representing a vertical distance of more than 400 feet.

In the following pages, wherever possible, the nomenclature of Swallow has been followed, and thereby as much attention given to the laws of priority as seems possible. But, contrary to our desire, we have been forced to substitute names in the place of many used by Swallow on account of the great entanglement into which he was led, due, of course, as above stated, to his lack of opportunity.

Prof. G. C. Broadhead, of Missouri, has been an active worker in geology for nearly half a century. He was a member of the Missouri Geological Survey in 1872, and published a long and valuable report on the Coal Measures of Missouri. Naturally this brought him in contact with Kansas geology, and much of what he wrote of Missouri is applicable to Kansas.

In the Missouri Survey Report for 1872, beginning on page 88, Broadhead gives a "General Vertical Section of Upper Coal Measures Rocks Below the Atchison County Group." Following the custom of his time he gave numbers to each individual horizon, beginning at the top with number 224, and closing at the bottom of the section with number 72. The remainder of the list from 72 down to 1 is found elsewhere in the report, given as a section of the Middle Coal Measures and Lower Coal Measures. Broadhead occasionally gave names to these different formations, but as a rule simply gave a short description of them without suggesting a name. In treating the subjects he discussed, therefore, it is difficult not to ignore the few names he did suggest, on account of his lack of system in giving descriptions.

Professor Broadhead also published many reports and short papers elsewhere. He probably knew more details regarding the geology of eastern Kansas and western Missouri than any other person up to the date of the organization of recent State Surveys in these two states. It is difficult to find any phase of geology connected with eastern Kansas and western Missouri upon which he has not touched.

Prof. B. F. Shumard did little, if any, actual work in Kan-

sas, excepting in his paleontological investigations of material sent him. His name is associated intimately with those of Meek, Hawn and Swallow in early publications, particularly in connection with discussions of the Permian in the Great West.

Prof. J. S. Newberry, like Shumard, did little, if any, work in Kansas, but his name is intimately connected with discussions on Permian geology in those early days. Professor Newberry was one of the best and greatest workers America ever produced. In addition to his duties as professor of geology in Columbia University he found time to traverse almost the entire continent and to write reports aggregating thousands of pages. His closest relation to Kansas was in connection with his explorations in New Mexico and the Southwest.

During the second division of time, as outlined early in these pages, no very extensive or continuous work was done in the entire state; but nevertheless in the aggregate a great deal of valuable knowledge was gained. Prof. B. F. Mudge, while located at the State Agricultural College, at Manhattan, and afterwards while making collections for eastern institutions, published a number of papers devoted to different phases of Kansas geology, some of which were particularly valuable. He published principally in the biennial reports of the secretary of the State Board of Agriculture, but also we find papers by him in the reports of Dr. F. V. Hayden for 1876 and 1877, in different volumes of the Kansas Academy of Science, and in McFarland's American Geological Railroad Guide for 1879. One of his most noted reports is on the lead- and zinc-mines of Galena and vicinity. He also made geological sections across the entire state and published a preliminary geological map.

Mr. O. St. John, formerly connected with the Iowa State Geological Survey and Doctor Hayden's Geological and Geographical Survey of the Territories, published a paper of a general nature on "Kansas Geology" in the Fifth Annual Report of the secretary of the State Board of Agriculture in 1887. Soon afterwards he became engaged in private geological work, whereupon his publications ceased, much to the regret of all geologists acquainted with him.

Prof. Robert Hay was a veteran Kansas geologist. He began publishing papers on Kansas geology in the Transactions of the Kansas Academy of Science as early as 1882 and continued without interruption until the time of his death. He

also published in the biennial reports of the secretary of the Kansas State Board of Agriculture, in the Bulletins of the American Geological Society, and later published a few papers as bulletins of the United States Geological Survey, and in a number of other places.

Chancellor F. H. Snow, of the University of Kansas, has done so much work in Kansas geology that it is difficult to describe it in a paragraph. Early in his career as professor of natural sciences in the University he began gathering fossils in the state, principally, though not wholly, vertebrate fossils in western Kansas. The results of his various discoveries were published from time to time in the Transactions of the Kansas Academy of Science and elsewhere. He has written no long monographic articles, but his various papers, if collected together, would constitute an important chapter in the literature of Kansas geology. Probably his most noted individual discovery was made in 1878 when he found the fossil skin of a Cretaceous reptile showing in a very perfect manner the scaly covering of the reptile's body. His work as a museum builder was much greater than that of a writer on geology or paleontology, and the excellent museum of vertebrate and invertebrate fauna now in the University of Kansas is very largely due to his individual efforts.

Prof. G. E. Patrick, while occupying the chair of chemistry and physics in the University of Kansas, from 1874 to 1883, inclusive, published a number of papers in connection with various phases of economic geology in Kansas, principally using the Transactions of the Kansas Academy of Science as a medium of publication.

Mr. Joseph Savage, of Lawrence, formerly connected with the Hayden survey, published a number of short papers on different points in Kansas geology in the Transactions of the Kansas Academy of Science.

Prof. S. W. Williston, who formerly occupied the chair of paleontology in the University of Kansas, and now holds a similar position in the University of Chicago, published a number of papers in the Transactions of the Kansas Academy of Science, dealing principally with phases of Kansas paleontology. He published many papers on paleontology in the Kansas University Quarterly, all of which had more or less of general geology. He was a member of the University Geological Survey of Kansas under its present organization and

issued volumes IV and VI of the state reports, and also contributed an article to volume II. Since his removal to Chicago he has continued his investigations of Kansas paleontology.

Professor E. D. Cope, of Philadelphia, in his position as chief paleontologist to Dr. F. V. Hayden, made extensive investigations in the Great West, including portions of Kansas. His publications are very numerous and confined principally to reports issued under the Hayden Survey and to individual papers published in the *American Naturalist.* Two of these particularly refer to western Kansas—one on "The Fossil Reptiles and Fishes of the Cretaceous of Kansas," published in 1871, and another "On the Geology and Paleontology of the Cretaceous of Kansas," published in 1872. Professor Cope did his work principally by subjects rather than by geographic areas, and, as a result, touched upon Kansas geology and paleontology in many ways and in many different papers.

Dr. Joseph Leidy, of Philadelphia, a vertebrate paleontologist of great repute in his day, scarcely invaded Kansas, excepting by way of identification of Kansas fossils sent him for that purpose.

Prof. O. C. Marsh, of Yale University, a vertebrate paleontologist ranking with Professor Cope, sent numerous collecting parties into the rich fields of western Kansas which gathered many valuable fossils that were added to the museums of Yale University. In this way Professor Marsh's name will always be connected with Kansas paleontology.

Prof. J. A. Udden, at one time connected with Bethany College, Lindsborg, Kan., now of Moline, Ill., did considerable work in Kansas geology while located at Lindsborg. His work was confined principally to paleontology and archeology.

The third period of geological investigation, as already outlined in these pages, begins with the revival of state surveys in Missouri and Kansas. Workers on the Missouri Survey did nothing in Kansas proper, but almost all their investigations along the border lines, both in the Coal Measures and in the lead- and zinc-mining districts, had a direct bearing on Kansas geology. One might go even farther and make the same remark regarding the recent geological survey of Iowa. The Coal Measures of Kansas extend across the western part of Missouri and up into Iowa. It is probable that any systematic classification of formations applicable to one of these states is

equally applicable in either of the others, although this has not been fully established. The great coal basin west of the Mississippi, which extends southward by way of Iowa, Missouri and Kansas, also covers a part of Oklahoma and veers around to the east into Arkansas, south of the Arkansas river.

Dr. C. R. Keyes, while assistant state geologist of Iowa, and later as state geologist of Missouri, published a number of papers in different state reports and also in current geological magazines, many of which had a bearing on Kansas geology. Although never having done any actual work in the state, his labors in adjoining areas made it possible for him to draw numerous inferences and to take part in discussions of classification and introduction of names in the Kansas Coal Measures. Usually his investigations were of a general character rather than specific, and his boundary lines between two contiguous horizons were rarely sharply defined. He suggested many names, covering almost the entire Carboniferous, but his descriptions were never detailed enough for his readers to locate positively the boundary lines embracing the parts named. He revived Broadhead's term, "Bethany Falls limestone," leaving out the "Falls" applied originally by Broadhead, to one individual limestone horizon and spread it over a complex of limestones and interbedded shales which he limited both above and below in such general language that workers in Kansas have never been able to know definitely where the boundary lines should be drawn; and this, too, after the Kansas Survey had, by most careful work, traced the outcroppings of many of these limestones and applied names to them. In general his publications have tended to confusion rather than to clearer interpretations in Kansas geology.

Prof. C. S. Prosser has been intimately connected with the development of Kansas geology for something over ten years. His first and greatest work in the state was done under the auspices of the United States Geological Survey in the area covered by the Cottonwood folio. This brought him at once in contact with the Upper Carboniferous and the Permian of the state, and nearly all the literature covering these subjects which has appeared during this period has come from his pen. He has done a valuable work in correcting certain errors that were creeping into our literature and in setting us right on a number of mooted questions. He has done practically all the work in establishing the boundary line between the Permian

and Upper Coal Measures of the state, based both on paleontology and stratigraphy, having identified the various fossil forms himself and, to a great measure, traced in the field in a detailed way the stratified conditions as we now find them.

Dr. George I. Adams, for a few years after graduation from the University of Kansas, gave his time and energies to the present University Geological Survey of Kansas. For four successive summers he worked partly on the detailed stratigraphy of the Coal Measures and partly on the stratigraphy and ground-water conditions of the western part of the state. After leaving the State Survey he joined the United States Geological Survey. Either alone or with others he published Bulletins 184, 211, and 238. Bulletin 211 is a general review of the oil-fields between the Mississippi river and the Rocky Mountains, including those of Kansas and Oklahoma. In No. 211 Doctor Adams gives an elaborate review of methods and nomenclature employed by different parties in the Mississippi valley, particularly in Kansas and Oklahoma, and later in the report reviews the entire system of naming previously suggested by different members of our State Survey, some of which names he adopts and others he replaces by names of his own. Unfortunately, subsequent investigation has shown that he was led into error in a number of instances in matters of correlation, due to a lack of proper detailed information. Bulletin No. 238, largely written by Doctor Adams, is devoted entirely to the Iola Quadrangle area. This area was resurveyed by the United States Geological Survey, so that an excellent topographic map is now available, and the geological and economic features of it were reinvestigated by Adams and others in the summer of 1903.

It is unfortunate to have to record that in the maps of this bulletin prepared by Doctor Adams a slight error was made in connection with the Chanute shales and Iola limestone, an error already corrected by additional field work performed jointly by Mr. Millard K. Shaler, of the United States Geological Survey and Rev. John Bennett, of the State Survey, which corrections are herein embodied.

Dr. J. W. Beede has done a great deal of work in Kansas geology during the last few years. In volume VI of the State Survey reports he published a paper on the "Invertebrate Paleontology of the Carboniferous of Kansas." Since that date he, in connection with Dr. A. F. Rogers, while working

for the State Survey, has made a complete faunal section from the base of the Coal Measures to the Permian, and has published the results in a series of articles in the University Science Bulletin, an outline of which is included in this volume. Also, he has rendered valuable assistance in the preparation of geological maps of the state, published for the first time with this report.

Dr. A. F. Rogers began his work in Kansas geology in connection with the investigations of lead and zinc ores and is the author of part III, volume VIII, Special Report on Lead and Zinc, just issued from the press. This paper is devoted entirely to the mineralogy of the region. Subsequently he assisted Dr. J. W. Beede in field and laboratory work in preparing their paper on the faunal section of the Coal Measures of Kansas mentioned above.

Rev. John Bennett first began working for the University Geological Survey in the summer of 1894. Previous to this time, while residing at Fort Scott, Kansas City, Savannah, and Cameron, Mo., he had become intimately acquainted with the invertebrate paleontology of the Coal Measures within the environs of his different places of residence. He has been connected with the Kansas Survey intermittently from 1894 to the present time, and has done more field-work in tracing out the individual horizons than any other one person. His first publications on Kansas geology consist of four papers in volume I of the University Geological Survey reports. Since that time he has been identified practically with every piece of work done by the University Geological Survey of Kansas which has a bearing in any way on the stratigraphy of the Coal Measures. At irregular intervals during the last few years he has been employed by the United States Geological Survey to assist in certain stratigraphic investigations made by Doctor Adams, which work took him partly into the Coal Measures of Kansas and partly into the areas covered by the same formations in Oklahoma.

Prof. W. N. Logan worked with the University Geological Survey of Kansas during the summer of 1896 and prepared a report covering the results of his field-work which was published in volume II of University Geological Survey reports. Later, he spent a few weeks in assisting in the stratigraphic work in the Coal Measures. Later he held the position of professor of geology in St. Lawrence University, New York,

from which place he went to the Agricultural College of Mississippi and became state geologist.

Prof. E. B. Knerr, of Midland College, Atchison, worked with the University Geological Survey during the summer of 1895. He made a geological section from Atchison west entirely across the Coal Measures and the Permian, and published the same in volume I, University Geological Survey reports.

Prof. E. H. S. Bailey, head professor of chemistry in the University of Kansas, for a number of years has made a specialty of mineral waters in Kansas and elsewhere. He published volume VII of the University Geological Survey reports, which is devoted entirely to the mineral waters of the state.

Dr. E. C. Case, of Ann Arbor, Mich., for a number of years was a student at the University of Kansas in both the undergraduate and graduate departments. In this connection he made a number of investigations, particularly in western Kansas. In volume IV of the University Geological Survey reports he published a paper on one of the divisions of fossil turtles.

Dr. C. E. McClung, now of the zoölogical department of the University of Kansas, also published a paper in volume IV on Kansas chalk, dealing principally with the micropaleontology of the same.

Dr. G. P. Grimsley for a number of years was connected with the University Geological Survey, making a special study of gypsum and its products. He prepared the greater portion of volume V of the Survey reports, which is devoted entirely to gypsum and the various gypsum industries.

Professor Erasmus Haworth began the work of the University Geological Survey of Kansas during the summer of 1893 and has worked at it continuously from that time to the present. In his capacity as state geologist he has had general oversight of all the work done by the Survey excepting that done by Professors Williston and Bailey and their assistants.

In addition to the above workers a large number of advanced and graduate students have devoted from one to two summers to work on the Geological Survey, some of whom have been joint authors in various papers and reports, but a number of whom have not yet reached such a prominence. Some of them have grown into geologists of note; a few of them have taken up other lines of work and become widely-known authorities,

and one, Mr. Carl C. Cramer, is no longer living. He was an honest, conscientious and able worker for a beginner, and did most excellent work during the summers of 1902 and 1903, but fell a victim to disease, not living to see the results of his labors appear in print. The following-named gentlemen are the ones referred to above. Each of them did good service as a volunteer worker, usually having no compensation excepting the gratification of a desire to study nature by a close personal contact with one of the great branches of nature study, and a feeling that by giving his time in this way he was contributing as best he could to the welfare of the state and, in a degree, to the promotion and dissemination of knowledge. Frank Brook, Charles F. Brook, Fred. J. Cambern, E. C. Chaney, T. L. Eyerly, Frank Gephart, J. Z. Gilbert, C. N. Gould, Walter Griffiths, John G. Hall, H. J. Harnley, T. H. Hooper, E. E. Hudson, Victor Iles, C. D. Ise, M. Z. Kirk, Dr. W. N. Logan, D. F. McFarland, George L. Metcalf, Dr. B. L. Miller, J. H. Patton, W. H. H. Piatt, B. L. Pampelly, W. E. Ringle, A. J. Smith, Dr. S. Z. Sharp, J. W. Shideler, Dr. E. H. Sellards, Alban Stewart, E. G. Swem, E. A. White, and Prof. J. A. Yates.

Judge E. P. West, of Kansas City, was connected with the museum of the University of Kansas during the last few years of his life. In this capacity he made a number of investigations in Kansas geology and published a number of papers in the Kansas City *Review of Science and Industry.*

Prof. W. F. Cragin for a number of years was connected with Washburn College, Topeka, during which time he made a great many investigations in Kansas geology and published many papers on various phases of the subject. His publications were principally in current scientific magazines, Transactions of the Kansas Academy of Science, and *Washburn College Laboratory Bulletin,* a publication originated and conducted by Professor Cragin. They cover a wide range of subjects, and the state is greatly indebted to him for his extensive work.

CHAPTER III.

GENERAL STRATIGRAPHY.

By ERASMUS HAWORTH and JOHN BENNETT.

AS FAR as developments thus far have gone in Kansas, oil and gas are confined to the Coal Measures, although many are inclined to a belief the same may be found in deeper formations. Thus far all such attempts have proven failures in Kansas, while in the vicinity of Muskogee, Okla., some oil has been obtained by such deep drilling. This makes it desirable to give as complete an exposition as possible of the Mississippian and underlying formations throughout the area discussed.

A great deal of attention has been given to the Cretaceous of Kansas with a hope that valuable discoveries might be made here. A few wells have been drilled in the western part of the state, some of which have passed entirely through the Cretaceous and into the underlying Permian. But none of them have obtained either oil or gas. For this reason, the only attention given in this report to the geology of the Permian and Cretaceous is the general geologic map of the state printed in colors.

The Mississippian Series.

The Mississippian series includes a complex of limestones and shales. They are exposed over a zone irregular in width along the Mississippi river from near Davenport south to beyond St. Louis and around the borders of the Ozark area south of the Missouri river from St. Louis westward to Sedalia and southwestward to the Joplin area and Galena in Kansas; thence south and southeastward, covering nearly all of the lands belonging to the Quapaw, Peoria, Ottawa, Shawnee, Modoc, Wyandotte and Seneca Indians, and the eastern part of the holdings of the Cherokees and a considerable portion of northwestern Arkansas.

The strata dip away from the Ozark area on all sides. Thus,

on the north they dip to the north, on the west they dip to the west, etc. Along the south line of Kansas the maximum dip is a little south of west, and further south, in the Cherokee Nation, it gradually veers to the southwest.

The Mississippian series is not composed entirely of limestone, as is popularly supposed by well-drillers and oil-operators. On the contrary, here and there throughout are thin beds of shales, and quite likely sandstone may be found at many places. Beneath the Mississippian one would ordinarily expect to find in a descending order the Devonian, Silurian, Ordovician, and Cambrian. Whether or not they occur under the oil-fields will remain problematic until they are actually discovered. Throughout this oil region, therefore, a drill might pass through the following series successively: Coal Measures, Mississippian, Devonian, Silurian, Ordovician, Cambrian, and into the fundamental granites or gneisses.

East of the oil regions in the Ozark area these underlying rock masses come to the surface and have been studied with great care by various geologists. It seems that the Devonian system is almost entirely wanting in the Ozark region, which would lead one to suspect it would be wanting likewise under the oil-beds. In his report on Green county, Missouri, Professor Shepard[3] gives the following scheme of classification for the rocks exposed in that county. If the term Coal Measures was substituted for the term Des Moines used by Shepard, the sequence just given for the oil-fields would be the same as that given in Shepard's classification.

Doctor Adams,[4] in writing about the Mississippian or lower systems or series for the entire Ozark region, gave the following scheme, which differs but little from that of Shepard.

3. Shepard, Prof. E. M.: Mo. G. S. Rep., vol. XII, p. 49. Jefferson City, 1898.

4. Adams, Dr. George I.: U. S. G. S., 22d Ann. Rep., pt. II, pp. 76-94. Washington, 1901.

SHEPARD'S TABLE OF GEOLOGICAL FORMATIONS IN GREEN COUNTY, MISSOURI.

System.	Series.	Stage.	Formations.
Carboniferous.	Des Moines.	Cherokee.	Graydon sandstone.
	Mississippian.	Augusta.	Upper Burlington limestone. Lower Burlington limestone.
		Kinderhook.	Chouteau limestone. Hannibal shales. Louisiana limestone.
Devonian.		Hamilton.	Phelps sandstone. Sac limestone. King limestone. Black shale.
Silurian.	Ozark.		First magnesian limestone. First sandstone. Second magnesian limestone. Second sandstone. Third magnesian limestone.

ADAMS'S GENERAL GEOLOGIC SECTION OF THE OZARK REGION.

Age.	Missouri section.	Arkansas section.	Classification of rocks.
Tertiary.	Represented in southeastern Missouri.	Represented in eastern Arkansas.	
Upper Carboniferous.	Cherokee shales, Haworth. Graydon shales, Shepard.	Millstone grit.	Undifferentiated shales and sandstones of the Carboniferous system.
Lower carboniferous.	Chester, St. Louis, Warsaw, Keokuk. (Mississippi river section.)	Boston group; Batesville sandstone; Fayetteville shale of Arkansas survey.	
	Upper Burlington, Shepard. Lower Burlington, Shepard.	Boone chert and limestone, including the St. Joe limestone of Arkansas survey.	Limestones of the Mississippian series.
	Pierson limestone, Weller. Northview shales and sandstone, Weller. Sac limestone, Weller. Eureka shale.	Sylamore sandstone and Eureka shale of Arkansas survey.	Black shales of the Devono-Carboniferous system.
Upper Silurian.	Either not represented or not differentiated.	St. Clair limestone, Williams. Cason shale, Williams.	
Lower Silurian or Ordovician.	Hudson river. Trenton. Roubidoux sandstone, Nason. Gasconade sandstone, Nason. Lower limits not given.	Polk Bayou limestone, Izard limestone, saccharoidal sandstone, magnesian limestone, cherts, etc., of Arkansas survey.	Limestones and sandstones of the Cambro-Silurian system.
	Lesueur limestone, Keyes. Fredericktown limestone, Keyes. LaMotte sandstone, Keyes.	Either not represented or not differentiated.	
Archæn.	Iron Mountain porphyry. Knob Lick granite.	Not represented.	Pre-Cambrian crystallines.

From the exposition (p. 59) it may be seen that one may reasonably expect to find about 2000 feet of stratified rock, plus or minus 500 feet, below the bottom of the Coal Measures and above the fundamental granites or gneisses. In part we know what the upper portion of this 2000 feet is like, as numerous deep wells have penetrated it to various distances. It is probable, also, that the uppermost part of the Mississippian as exposed at Galena to the west, where protected from erosion by the overlying Coal Measures in the oil-fields, is younger than that exposed at Joplin and further east, for recent erosion may have removed a very considerable portion of the upper Mississippian in that region. From paleontologic evidence it seems that the uppermost rocks at Galena belong to the Keokuk or younger formations which overlie the Burlington.

Deep wells have been drilled at Neodesha, Caney, Cherokee, Stone City, Girard, Weir City, Iola, and a number of other places, records of some of which are here included, with plates or figures made from the drawings of the same. One is at Cherokee, Kan., 908 feet deep, which struck the top of the Mississippian limestone at 352 feet and therefore went 556 feet below its surface; one at Stone City, a few miles southwest of Cherokee, with a total depth of 856 feet, which struck the top of the Mississippian at 376 feet and therefore went 480 feet beneath its surface; one at Weir City, which went 210 feet below the upper surface of the Mississippian; one at Girard, with a total depth of 900 feet, which struck the Mississippian at 450 feet and therefore went 450 feet beneath its upper surface; and one at Neodesha, with a depth of 2412 feet, struck the Mississippian at 1090 feet beneath the surface and therefore went 1322 feet beneath its upper surface.

This latter well record is important because more care was given it than is given the ordinary well. It was drilled by the Forest Oil Company as a test well, and was begun almost immediately after they purchased the Neodesha oil properties from Guffey & Galey. This is the same company which drilled the Bedell deep well in West Virginia some years before, which well still remains the deepest boring on the American continent, having reached a total depth of 5575 feet. Mr. Patterson, still with the company, had immediate charge of the well and kindly kept duplicate sets of the drill-cuttings, one of which is preserved in the office of the Prairie Oil Com-

pany, at Neodesha, and the other presented to the museum of the State University. Immediately upon their receipt a superficial examination was made, the results of which were given to the public. But no detailed examination was made until recently. In the preparation of volume VIII, this series, a very detailed examination of every sample cutting was made, in order that a thoroughly reliable record could be built up and put into permanent form.

It should be stated that beneath the Mississippian limestone is a great mass of calcareous sandstones and arenaceous dolomitic limestones. From the drill cuttings alone sometimes it was difficult to determine just what names to use. The dolomitic limestones were thoroughly crystallized, and were, therefore, composed largely of little granular crystals of dolomite, which were broken up by the drill, and strongly resembled sandstone cuttings. It was only by chemical and microscopical examination that they were distinguished from the sand grains. In fact, the sandstones and limestones grade into each other in such a way that scarcely a sample of the limestone could be found which did not contain water-worn sand grains, and scarcely a sample of sandstone could be found which did not contain variable amounts of calcium or magnesium carbonates.

The last material passed through by the drill was a very hard, compact sandstone, which the drillers called granite. It proved to be a very interesting rock. Some of the samples of it carry a perceptible amount of feldspar, which increases its similarity to granite. Also, many of the samples are composed almost entirely of angular fragments of quartz, showing that the sand grains were cemented together by silica, producing a genuine quartzite which yielded angular fragments by the action of the drill bit. But all the way through rounded sand grains were present in sufficient quantity to preclude the idea that this material was granite or other eruptive rock.

A number of well records follow, which may be read in connection with a study of the figures accompanying them.

Cherokee Water Well.

Reported by W. E. Turkington, Cherokee, Kan.

Material.	Thickness of strata.	Total depth.
Soil and soapstone	20 feet.	20 feet.
Shale, 10 inches coal	5 "	25 "
Black shale	34 "	59 "
Slate	10 "	70 "
Hard limestone	10 "	80 "
Sandstone	10 "	90 "
Slate, 16 inches coal	6 "	96 "
Black slate	6 "	102 "
Slate	28 "	130 "
Slate	10 "	140 "
Sandstone	3 "	143 "
Shale	10 "	153 "
Coal and slate mixed	5 "	158 "
Hard limestone	7 "	165 "
Slate and sandstone	15 "	180 "
Sandstone	10 "	190 "
Black slate	10 "	200 "
Slate and fire clay	15 "	215 "
Soapstone	10 "	225 "
Sand and limestone	10 "	235 "
Dark shale	110 "	345 "
Coal	1 "	346 "
Shale and pyrite	6 "	352 "
Lime and flint showing oil	4 "	356 "
Lime and flint	6 "	362 "
Limestone	48 "	410 "
Limestone	90 "	500 "
Hard flint	30 "	530 "
Lime and sand	70 "	600 "
Magnesium limestone	50 "	650 "
Flint and limestone	25 "	675 "
Limestone	5 "	680 "
Flint and sand	15 "	695 "
Limestone	10 "	705 "
Blue slate	10 "	715 "
Limestone	30 "	745 "
Sand and good showing of water	40 "	785 "
Sand and water	5 "	790 "
Lime and sand mixed	55 "	845 "
Lime and sand mixed	20 "	865 "
Limestone and water	10 "	875 "
White flint and sand	10 "	885 "
Lime, sand, and flint	23 "	908 "

Neodesha Deep Well.

Record determined by E. Haworth and G. F. Kay, from a study of drill cuttings supplied by Mr. E. T. Patterson, who superintended the drilling and saved duplicate samples.

Material.	Thickness of strata.	Total depth.
Surface soil and clay	33 feet.	33 feet.
Sandstone, fine grained, slightly calcareous	34 "	65 "
Shale, gray, calcareous and arenaceous	5 "	70 "
Shale, gray, calcareous	43 "	113 "
Limestone, light colored	19 "	132 "
Shale, bluish	15 "	147 "
Limestone, light colored	51 "	198 "
Limestone with black shale	5 "	203 "
Sandstone, fine grained	67 "	270 "
Limestone, light colored	21 "	291 "
Shale, bluish	37 "	328 "
Limestone with shale	16 "	344 "
Shale, black	29 "	373 "
Limestone, arenaceous	79 "	452 "
Shale	105 "	557 "
Limestone with bluish shale	47 "	604 "
Shale, black, calcareous	3 "	607 "
Limestone, shaly	15 "	622 "
Shale, slightly calcareous	33 "	655 "
Limestone with some shale	25 "	680 "
Shale, dark, calcareous	153 "	833 "
Shale, bluish, slightly calcareous	3 "	836 "
Sandstone	4 "	840 "
Shale, bluish	4 "	844 "

NEODESHA DEEP WELL—*continued.*

MATERIAL.	Thickness of strata.	Total depth.
Shale, dark	11 feet.	855 feet.
Shale, calcareous	38 "	893 "
Shale, black	10 "	903 "
Shale with some sandstone	27 "	930 "
Shale, black	38 "	968 "
Sandstone with some shale	18 "	986 "
Sandstone, light colored	8 "	994 "
Sandstone, white, slightly ferruginous	27 "	1021 "
Sandstone, very ferruginous	35 "	1056 "
Shale, black	20 "	1076 "
Shale, bluish	14 "	1090 "
Chert with shaly material	11 "	1101 "
Limestone, arenaceous	12 "	1113 "
Limestone, arenaceous	6 "	1119 "
Shale, arenaceous	13 "	1132 "
Limsetone, cherty	12 "	1144 "
Limestone, arenaceous	4 "	1148 "
Limestone, cherty	73 "	1221 "
Limestone, arenaceous	11 "	1234 "
Limestone, cherty, ferruginous	6 "	1240 "
Limestone, arenaceous, ferruginous	13 "	1253 "
Limestone, cherty	85 "	1335 "
Limestone, with little shale	4 "	1342 "
Limestone, shaly	8 "	1350 "
Limestone, arenaceous	4 "	1354 "
Limestone, cherty	2 "	1356 "
Limestone, arenaceous, slightly ferruginous	2 "	1358 "
Calcareous shale	6 "	1364 "
Sandstone, cherty	3 "	1367 "
Sandstone, cherty, calcareous, ferruginous	93 "	1460 "
Limestone, cherty	4 "	1464 "
Sandstone, fine grained	10 "	1474 "
Sandstone, calcareous	8 "	1482 "
Limestone, magnesian, arenaceous	8 "	1490 "
Sandstone with calcium and magnesian carbonates	37 "	1527 "
Sandstone with considerable magnesian carbonate	7 "	1534 "
Sandstone, cherty, with magnesian carbonate	10 "	1544 "
Sandstone with considerable magnesian carbonate, part cherty and part somewhat ferruginous	45 "	1589 "
Limestone, magnesian, cherty	3 "	1592 "
Sandstone with magnesian carbonate	4 "	1596 "
Limestone, cherty	2 "	1598 "
Sandstone with magnesian carbonate	5 "	1603 "
Limestone, magnesian, cherty	35 "	1638 "
Limestone, magnesian, arenaceous	43 "	1681 "
Limestone, magnesian, cherty	3 "	1684 "
Limestone, magnesian, arenaceous	9 "	1693 "
Sandstone with magnesian carbonate	7 "	1700 "
Limestone, magnesian, arenaceous	8 "	1708 "
Sandstone with magnesian carbonate	67 "	1775 "
Limestone, magnesian	10 "	1785 "
Limestone, magnesian, arenaceous	5 "	1790 "
Sandstone, cherty, with magnesian carbonate	5 "	1795 "
Sandstone, fine grained, with magnesian carbonate	39 "	1834 "
Sandstone, white	17 "	1851 "
Sandstone with magnesian carbonate	5 "	1856 "
Limestone, magnesian, arenaceous	38 "	1894 "
Limestone, magnesian, cherty	19 "	1913 "
Limestone, magnesian, arenaceous	23 "	1936 "
Limestone, magnesian, cherty	21 "	1957 "
Limestone, magnesian, arenaceous	22 "	1979 "
Sandstone, cherty, with magnesian carbonate	4 "	1983 "
Sandstone with magnesian carbonate	4 "	1987 "
Limestone, magnesian, arenaceous	160 "	2147 "
Limestone, magnesian, arenaceous	35 "	2182 "
Sandstone, white, part coarse and part fine	90 "	2272 "
Sandstone, coarse, with some feldspar	5 "	2277 "
Sandstone, coarse, some of quartz, angular, an appreciable amount of feldspar	5 "	2282 "
Sandstone, fine grained, much of the quartz angular, some feldspar	3 "	2285 "
Sandstone, coarse, the grains distinctly water-worn, considerable gray-colored feldspar	5 "	2290 "
Sandstone, the quartz in many cases angular, some feldspar and a few scales of mica	6 "	2296 "
Sandstone, white, fine grained, the grains mostly angular,	5 "	2301 "
Sandstone, much of quartz is angular, some pink feldspar,	2 "	2303 "

NEODESHA DEEP WELL—*concluded.*

MATERIAL.	Thickness of strata.	Total depth.
Sandstone, fine grained	2 feet.	2305 feet.
Sandstone, many grains well rounded, considerable gray feldspar	7 "	2312 "
Sandstone, fine grained, angular	4 "	2316 "
Sandstone, quartz quite angular, pink fragments of feldspar	5 "	2321 "
Sandstone with pink feldspar	2 "	2323 "
Sandstone, fine grained	3 "	2326 "
Sandstone with pink feldspar	2 "	2328 "
Sandstone, much of the quartz angular, some feldspar	3 "	2331 "
Sandstone, quartz mostly angular, pink feldspar fragments	47 "	2378 "
Sandstone with some feldspar	10 "	2388 "
Sandstone, many of the fragments of quartz angular, but some well rounded	2 "	2390 "
Sandstone, fine grained, most of the quartz angular, some feldspar	22 "	2412 "

STONE CITY WELL.

Reported by BAILEY & WAUGH, drillers. Forwarded by COL. W. B. STONE, Galena, Kan., December 8, 1900.

MATERIAL. Commencing at 300 feet.	Thickness of strata.	Total depth.
Gray shale	20 feet.	320 feet.
Gray sand shale	5 "	335 "
Black shale	15 "	340 "
Coal	8 inches.	.....
Gray shale	12 feet.	353 feet.
Black shale	8 "	361 "
Coal	1 "	362 "
Black shale containing mundic	9 "	371 "
Black shale with streaks of flint	5 "	376 "
White flint and gray limestone with streaks of sand	20 "	396 "
Gray-mottled flint, with showing of lime	100 "	496 "
Lime	50 "	546 "
Lime and flint	20 "	566 "
Flint and cotton rock (decomposed flint)	10 "	576 "
Flint	15 "	591 "
Flint and zinc ore	5 "	596 "
Blue flint, lime, and sand (known as bed-rock)	20 "	616 "
Blue flint and gray sand (among mines)	100 "	716 "
Lime, very solid at first, becoming thinner in strata, and getting softer with depth	80 "	796 "
Fine-grained, hard, white sandstone	4 "	800 "
Fine-grained, hard, gray sandstone	8 "	808 "
Fine-grained, hard, brown sandstone	4 "	812 "
Brown sand with openings quite porous in places	36 "	848 "
Brown and gray sand in thin strata, filled between with putty-like substance, color gray, resembling talc	8 "	856 "
Total depth	856 feet.	856 feet.

WEIR CITY WATER WELL NO. 2.

Reported by A. B. COCKERELL, May 25, 1897.

MATERIAL.	Thickness of strata.	Total depth.
Soil and clay	15 feet.	15 feet.
Sandstone	5 "	20 "
Slate	10 "	30 "
Coal	3 "	33 "
Fire clay	3 "	36 "
Slate	75 "	111 "
Coal	14 inches.	112 " 2 inches.
Fire clay	2 feet.	114 " 2 "
Slate	100 "	214 " 2 "
Coal	2 "	216 " 2 "
Fire clay	2 "	218 " 2 "
Slate	62 "	280 " 2 "
Flint	150 "	430 " 2 "
Sand flint	40 "	470 " 2 "
Granite*	20 "	490 " 2 "
Total depth	490 ft. 2 in.	490 feet 2 inches.

* It is exceedingly probable that the last item, granite, refers to a coarsely crystallized limestone, which is sometimes called granite in the lead and zinc mining district, and which is not granite at all, but limestone.—E. H.

GIRARD CITY WELL NO. 2.

Drilled by P. L. CROSSMAN, of Joplin, Mo. Commenced October 16, 1893; finished March 10, 1894. Record kept by JESSE T. BUFFINGTON, engineer and tool dresser.

MATERIAL.	Thickness of strata.	Total depth.
Soil	2 feet.	2 feet.
Clay, gummy and sticky	7 "	9 "
Limestone, white, without grit	16 "	25 "
Dark slate, first surface water	3 "	28 "
Limestone	12 "	40 "
Black slate	4 "	44 "
Soapstone with more water	6 "	50 "
Black limestone with pyrites of iron	1 "	51 "
White soapstone	9 "	60 "
Slate, getting darker from first to last	50 "	110 "
Dark soapstone	38 "	148 "
Slate with a little showing of coal	10 "	158 "
Hard slate with a little gas	2 "	160 "
Soapstone and slate, mixed with a small showing of coal,	15 "	175 "
Soapstone and slate mixed	36 "	211 "
A cross of soapstone and lime with some grit	1 "	212 "
White soapstone	5 "	217 "
Dark-colored soapstone	26 "	243 "
Slate, dark	9 "	252 "
Slate and shale mixed	4 "	256 "
Light soapstone	5 "	261 "
Dark soapstone	3 "	264 "
Light soapstone	6 "	270 "
A limestone formation, very hard	1 "	271 "
Light soapstone	1 "	272 "
Lime formation showing indication of soapstone being mixed with it	3 "	275 "
Light soapstone	8 "	283 "
Sandstone, gritty and dark colored	1 "	284 "
Dark soapstone	16 "	300 "
Gray sandstone, soft	2 "	302 "
Sandy shale, very gritty	8 "	310 "
Light soapstone	21 "	331 "
Dark soapstone	7 "	338 "
Light soapstone	31 "	369 "
Hard, sandy shale, where the well was cased, shutting off all the water above	7 "	376 "
Hard, sandy shale, bordering on sandstone	19 "	395 "
Coal	1 "	396 "
Light-colored shale	10 "	406 "
Slate, hard	5 "	411 "
Soapstone, light, firm and solid	6 "	417 "
Lime formation	1 "	418 "
Light soapstone, firm and solid	8 "	426 "
Dark soapstone	4 "	430 "
Light soapstone	8 "	438 "
Sandstone, hard	1 "	439 "
Light soapstone, firm and solid	5 "	444 "
Slate with pyrites of iron	6 "	450 "
Flint with lime shot in, very hard, and varying but little in color and texture, and cutting steel very fast	211 "	661 "
Limestone, almost pure, with pyrites of iron	4 "	665 "
Blue flint, very hard and sharp	2 "	667 "
Lime with a little flint, gradually getting softer, and toward the last containing some pyrites of iron	41 "	708 "
A change; light soapstone containing light pyrites of iron,	18 "	726 "
Hard shale	5 "	731 "
Gray limestone, hard toward the last	9 "	740 "
Slate with pyrites of iron	2 "	742 "
Gray sandstone, first water after casing; this water was very strong of sulphur	3 "	745 "
Limestone with hard stratum	51 "	796 "
Sandy limestone, changing in color some	12 "	808 "
Limestone, almost pure	4 "	812 "
Limestone and flint mixed	3 "	815 "
Limestone, varying in color	16 "	831 "
Limestone and flint mixed	6 "	837 "
Limestone, white	4 "	841 "
Limestone and flint	4 "	845 "
Limestone	8 "	853 "
Flint with a little lime, showing indications of water	4 "	857 "
Limestone, very hard	11 "	868 "
Lime and flint with indications of water	7 "	875 "
Flint and limestone	5 "	880 "

GIRARD CITY WELL NO. 2—*concluded.*

MATERIAL.	Thickness of strata.	Total depth.
Lime with some flint shot in	10 feet.	890 feet.
Flint with a little lime; getting harder and showing strong indications of water; and it is my opinion that this stratum furnishes the best supply of water in the well	10 "	900 "
Total depth	900 feet.	900 feet.

THE CANEY DEEP WELL.

In 1905 a stock company was formed in Caney for the purpose of exploring the formations lying underneath the Mississippian. Leases were readily obtained on a large acreage, principally lying to the west of Caney, so that should valuable results be obtained the company would be in a position to regain the heavy expenses of a deep well. Drilling was carried on as usual to a depth of 2800 feet, when all available funds gave out and likewise nearly all enthusiasm on the subject. Water in great quantities came in, which seriously interfered with further drilling. The bottom of the well is in a sandstone which shows considerable indication of oil. A pump was operated for a number of days in an attempt to pump the water out of the well. It lowered the water a few hundred feet and it was reported a considerable amount of gas escaped at that time, but not enough to drive the remaining water out of the well. Some parties confidently believe that if the water was out a strong gas-well would be obtained. This is entirely problematic, however, and by no means has been demonstrated. The small traces of oil at the bottom of the well and the small amount of gas obtained show that at least some oil and gas lie beneath the Mississippian limestone.

Unfortunately no one kept an accurate record of the well and therefore much valuable information was lost which might have been preserved had a little more care been exercised. The Mississippian limestone was reached at about 1600 feet, so that the well went about 1200 feet beneath the base of the Coal Measures, or a little less than the 1280 feet at Neodesha. Practically we are left where we were before the well was begun so far as any definite information is concerned, much to the regret of every one familiar with the facts.

IOLA DEEP WELL.

In 1906 a stock company was formed at Iola to drill a deep well in order to test the deep-seated formations. At the present writing, June, 1908, the well has attained a depth of about

THE IOLA DEEP WELL was finally carried to a depth of 3434 feet, at which depth is was abandoned about the first of October, 1908. This makes it the deepest well in the Mississippi valley west of St. Louis, and accordingly a correspondingly great interest attaches to it. The top of the Mississippian limestone was reached, in round numbers, at a thousand feet, making a full 2400 feet below this well-known horizon. The drill cuttings show positively that no massive rocks were found throughout the entire depth and that the drilling stopped still within the stratified rocks. The last thousand feet is nearly the same, being a very ferruginous sandrock with pebbles here and there through it in places large enough almost to warrant the use of the term conglomerate. The proportion of iron seemed to increase with the depth, and that from the very bottom had so much dark iron oxide in it that the whole mass was dark chocolate brown in color, but still composed of rounded sand grains coated with the iron oxide.

This well has an important bearing on the somewhat doubtful record of a deep well at Paola drilled years ago, supposedly to a depth of about 2500 feet. It was reported that granite was struck in this well at about 2250 feet. As the top of the Mississippian was reached at 1038 feet, this would give a total thickness of the stratified rock below this point of from 1200 to 1250 feet. Paola is a little less than sixty miles northeast of Iola. One can hardly believe the Paleozoic stratified rock beneath the top of the Mississippian would increase so much in so short a distance. Therefore, the Iola well casts considerable doubt upon the correctness of the report of massive rocks being found at Paola at a point less than 2300 feet beneath the surface. It is also reported that a deep well at Carthage, Mo., passed entirely through the stratified rocks and reached granite at a depth of about 2200 feet. This report is not negatived by the Iola well, because the latter has only gone a little over 200 feet below where we would expect to find the granite according to the Carthage well. We can understand how that the stratified rock may have increased as much as 234 feet in the distance between Carthage and Iola, and yet there is no more reason for suspecting such an increase than there would be to suspect a corresponding decrease.

E. H.

3200 feet. Drill-cuttings were preserved for every screw and were carefully examined, from which a tolerably accurate record of the well was obtained and is included herein. This well, like all the other deep wells now known, fails to furnish oil or gas in commercial quantities.

The above descriptions of deep wells penetrating the Mississippian and underlying formations have been given principally because it is important economically as well as theoretically to learn, if possible, whether or not these formations contain oil or gas in commercial quantities. It may be stated, also, that an added interest is attached thereto in connection with theories regarding the origin of oil and gas. Much money has been spent in Kansas based upon the belief that the Trenton limestone underlies this oil-field and is the original source of the oil and gas, from which it has escaped upwards through fissures in the overlying formations and was finally caught by the impervious Coal Measure shales, which was the dominating principle governing the present location of oil and gas pools. Others have believed that the oil and gas were formed at a still greater depth by chemical processes and escaped upwards from the crystalline rocks below and through fissures of the stratified rocks as just named. A more lengthy discussion of these theories will be found in the proper chapter in this volume.

UPPER SURFACE.

The upper surface of the Mississippian limestone in some places was greatly eroded during pre-Coal Measure time. This has been commented upon by various geologists, has been illustrated by drawings and photographs by different authors, and varied and important conclusions have been drawn from such effects. Already various irregularities of surface in southeastern Cherokee county have been described, which are probably due to this surface erosion. The extent of such erosion further to the northwest can only be conjectured, as the surface of the Mississippian soon becomes covered to a great depth with the overlying Coal Measures. It is known, however, that the upper surface is very decidedly irregular, and not infrequently two wells beginning on a level surface reach the Mississippian at surprisingly varying distances. A number of instances of this kind have come to light in the vicinity of Independence. In some instances wells less than half a mile apart, beginning at practically the same height above sea-level,

have reached the top of the Mississippian at distances as great as seventy-five feet, implying a very considerable erosion.

The importance of this question is connected principally with a study of shore lines during geologic time. The Mississippian rocks were formed under ocean water. While the surfaces were being eroded they were of course above the ocean water, and therefore the ocean shore had receded to the west. Later, when the Coal Measures were laid down, covering eroded surfaces, the shore lines again migrated eastward. If, during the erosion period, the shore line migrated very far to the west the eroded area likewise will extend farther west. But if, on the other hand, the eroded area forms a narrow stretch extending along the southeastern limit of the Coal Measures as we now find them, then the shore line immediately previous to Coal Measure time did not progress very far to the west. This latter condition seems to have prevailed.

The extent of erosion in Kansas, as far as is known, is not very great, and therefore does not imply a very long period between Subcarboniferous and Coal Measure time. There is a perfect conformity between the Coal Measure strata and the upper surface of the Mississippian in Kansas when viewed over wide areas, as is clearly shown by the geologic sections published in this report; but locally there are many lesser examples of nonconformity on a small scale, produced largely by an interperiod of erosion rather than by a marked difference in positions of bedding-plains of the Mississippian and Pennsylvanian. If, therefore, there were any considerable oscillations after the Mississippian limestones were formed and previous to Coal Measure time it is remarkable that the final state of equilibrium reached and maintained during the earlier part of Coal Measure time should place the surface of the Mississippian in a position so that no broad nonconformities should be produced. These conditions indicate, therefore, that the oscillations which resulted in leaving the Mississippian rocks above the sea and in again depressing them so they could be covered by Coal Measure strata were confined to slight vertical movements and to narrow limits along the coastal area, movements which did not materially affect the same rocks further oceanward.

DIRECTION OF INCLINATION.

The upper surface of the Mississippian floor dips to the west and northwest. Along the southern line of the state, from Galena to Caney, the dip is about twenty-five feet to the mile and probably a little greater than this southwest.

In a northerly direction the inclination gradually decreases, so that in a line from Galena to Kansas City it is not more than one and a half feet to the mile. The Mississippian has been reached by wells in many places in the interval between Caney and Kansas City, making it possible to study this surface throughout the entire distance.

The Pennsylvanian Series.

The Coal Measures of eastern Kansas have been studied in such great detail that we are now able for the first time to give a complete exposition of every individual limestone and shale formation from the base of the Coal Measures up to the Burlingame limestone, and, with equal accuracy, by grouping the thinner formations, can give the formations from the Burlingame limestone upward to the Wreford limestone. Prosser[5] has finally decided, from paleontological evidence, that the Wreford should be used as a division line between the Upper Coal Measures and the Permian.

The following generalized vertical section shows the succession of individual formations as above mentioned. To make these the more easily understood a drawing has been made to represent the geological column from the Mississippian to the top of the Cretaceous, as shown in plate I.

Plate VII*a*, VII*b* and VII*c* is a surface map of the eastern part of the state, showing in colors the outcropping lines of the principal limestone formations. Of course the interbedded shales will outcrop along the surface areas between the limestone outcropping lines. On this map are also marked the location of various vertical sections, made approximately at right angles to the outcropping lines. It is assumed that the observer is situated beyond the state line to the south and is looking north. The right-hand end of the drawing, therefore, is to the east and the left-hand to the west. The individual limestones and shales are represented as they are found in place.

Beginning at the south side of the state, plate VIII, figure 1,

5. Prosser, Chas. S.

is a vertical section from Vinita, Okla., to Sedan, Kan., and beyond, in Chautauqua county. It shows the Mississippian limestone coming to the surface at Vinita, with the Cherokee shales occupying the surface first to the west, then the Fort Scott and Pawnee limestones, followed successively by the various shales and limestones higher up, including the Oread and Lecompton limestones at the extreme western end of the section. Plate VIII, figure 2, is a vertical section from the south state line near Chetopa to Severy, in Greenwood county. It shows the Cherokee shales occupying the surface at the right-hand end of the section and higher formations regularly succeeding them westward, with the Burlingame limestone in the escarpment west of Severy; and a few of the upper lesser limestones beyond. Plate IX, figure 1, is a section from the east state line near Pittsburg, Crawford county, northwestward to Eureka and beyond in Greenwood county. It differs but little from the section in plate III, figure 2. Plate IX, figure 2, is a section from the state line near Fort Scott northwestward to near Burlington, with a slight change in direction at Iola. It shows the Fort Scott limestone at the surface on the east succeeded by the overlying formations in regular order to the Oread limestone at Burlington, in Coffey county. Plate X, figure 1, is a section from the state line near Pleasanton, in Linn county, northwestward to Emporia and beyond in Lyon county. This section shows the Pleasanton shales at the surface at the state line, succeeded by formations in regular order to the Cottonwood limestone on the extreme west. Plate X, figure 2, is a section from the east state line near Paola northwestward to Osage City, in Osage county, and beyond. It shows the Iola limestone on the extreme right, with succeeding formations up to and including the Burlingame limestone. Plate XI, figure 1, is a section from the east state line near Olathe westward to McFarland, in Wabaunsee county, and shows the Iola limestone occupying the surface at the state line succeeded by formations in regular order to the Cottonwood on top of the hills just south of McFarland. Plate XI, figure 2, is a section from Leavenworth westward to Mayetta, in Jackson county. It shows the Oread limestone capping the bluffs just west of Leavenworth, succeeded by limestone and shale in regular order, with the Burlingame limestone on the hilltops a few miles west of Valley Falls. The surface beyond this to the west is so covered with glacial loess

that no stratified rocks are exposed. Plate XI, figure 3, is a section from Saxton, Mo., five miles east of St. Joseph, to Hiawatha, in Brown county. It shows the Oread limestone on the surface at Saxton, the Burlingame limestone at Robinson, and a mantle of glacial drift at Hiawatha and in between.

Plate XII, figure 1, is a somewhat diagrammatic illustration of the Stanton-Allen limestone in a vertical section from Leavenworth to Caney. In this figure the vertical scale is much greater relatively than in figure 2 of the same plate and is included to represent the varying thicknesses of these two limestones at different places, and also the variation in thickness of the Vilas shales lying between them. With the single exception of the Drum limestone, so thick at Independence and growing thin so rapidly to the north, no other limestones in the state vary in thickness nearly so much as the Stanton and Allen limestones do. A full description of this variation is included in a description of the Allen limestone. The variable thickness of the Vilas shales lying above the Allen limestone is also well represented in this figure, a variation much greater than is commonly found in the shale-beds of eastern Kansas. Plate XII, figure 2, is a vertical geological section from Leavenworth to the south line of the state near Caney, covering the same distance shown in figure 1. It is drawn to a different scale, however, much more nearly the natural, and therefore the variations in thickness above alluded to could not well be represented.

Plate XIII is a vertical section northeast and southwest along the line of outcropping of the Burlingame limestone. It shows the Burlingame limestone as observable on the surface and the other limestones which outcrop to the east as they would appear in the section, provided they continued back westward in the same relative position and thickness shown along their respective outcropping lines. Of course we do not know to what extent they maintain these properties westward excepting as shown by various deep wells throughout the oil- and gas-fields. Many deep wells have been drilled, records of a goodly number of which are included in this volume. A careful study of these records reveals that the most, and probably all, of the limestone formations extend westward. Considerable difficulty has been encountered in getting well records which are accurate in detail. It is common for drillers to run together in one group a number of various limestone and shale-

beds, making it thereby impossible to interpret such records. But there is a practical unanimity in all the records regarding the heavier limestones and thicker shales. It seems that there is a tendency westward for the deep-seated limestones to grow thinner and shales correspondingly thicker. This is well shown in the deep wells at Topeka, McFarland and Le Roy. Plate XIII, therefore, should be looked upon as somewhat diagrammatic, and yet it is accurate to a comparatively high degree.

Records of as many deep wells are included in this report as seemed desirable for the complete illustration of all questions of stratigraphy herein set forth. Quite a number of them were published in volumes I and III of our State Survey reports, and are repeated here in order to make the exposition more complete. Necessarily, well records from the southern part of the state are more numerous than from the northern, due to the greater activity in the southern oil-fields.

On Names.

In earlier pages of this report is given a brief historical sketch of the geological work done in Kansas by various geologists from the earliest times down to the present. In this sketch is pointed out how the pioneer work of Hayden, Meek, Swallow and others was necessarily reconnaisance in nature, how after a fashion various names were given for various individual formations, and how it was found it was practically impossible to retain all of such reconnaisance names on account of errors in correlations made in those early days. This Survey has been criticized, friendly and otherwise, on different occasions on account of its apparent lack of regard for the laws of priority in the use of names. Without exception such criticisms have emanated outside the state[6] from parties poorly informed regarding the details of Kansas stratigraphy, and also regarding the work recently performed. Those interested in the subject are advised to compare carefully the outline given by Swallow in his report of 1866 with the detailed stra-

6. On page 122, in volume I, Neb. Geol. Surv., 1903, occurs the following: "In the classification of the Carboniferous beds of this region the more conspicuous pioneers are Swallow, Meek, Hayden and Broadhead. Swallow and Broadhead, in particular, have the undoubted right of priority, in that a full generation ago they studied the stratigraphy of Missouri, Kansas and Iowa to Nebraska, recognized and named the successive beds, and described them minutely and unmistakably. However, some later writers, ignorant of their work or ignoring it altogether, have rechristened some of the layers. In the last decade the stratigraphy of this same region has been studied by Keyes, Prosser, Williston, Beede, Haworth, Darton, and others." Comment is unnecessary.

tigraphy as it has now been worked out and exhibited in the maps and drawings of this report.

Another source of difficulty and apparent disregard to priority may be attributed to this Survey itself. Beginning in 1893, a number of geological sections were made in an east and west direction which was strictly pioneer work. The results of these labors were published, giving local geographic names to each formation as found along each section. Some time later, when it was possible to begin a series of correlations, necessarily some of the local names already in print had to be dropped. This gave occasion for criticism, although it is certainly the method followed by all geologists, the universal custom being to apply local geographic names, or sometimes numbers, to different formations, and later to correlate the formations for an entire area, retaining the most desirable names and abandoning others. Very naturally, in our zeal to give to the state at the earliest possible date much detailed knowledge partly for use by operators in the oil- and gas-fields, here and there slight errors crept into earlier correlations.

On Geological Divisions.

The lowest division in the geological column here considered is the Mississippian. As it covers the surface of so small an area in the state, and as thus far there is no oil or gas interest in that particular area, it is thought ill-advised to attempt any reclassification of subdivisions, even should any be necessary. Therefore, the subject will be treated in a general way and the classifications of Shepard and Adams in Missouri and Arkansas to the east will be given. In prospecting for oil and gas in Kansas, the Mississippian is found only with the drill, and the minor subdivisions, therefore, are of little importance to the person who finds them only at the bottom of a six-inch drill hole.

The Coal Measures proper of Kansas, that is, the entire rock mass lying between the Mississippian and the Permian, measure nearly 3500 feet in the southern part of the state and in general decrease northward to a little less than 3000 feet along the Kansas river section.

Viewed in a broad way, there is a certain variation in stratigraphic properties which may be used for the purpose of subdivision. We find heavy Cherokee shales at the base of the Coal Measures, above which is a mass of limestone with thin

interbedded shales; then the heavy Pleasanton shale-beds, sufficiently pronounced to mark prominent escarpments, that may be traced across the state; then another complex of heavy limestones and relatively thin shales, followed by a second heavy shale-bed, the Lawrence shales, with a correspondingly prominent scarp line entirely across the state. Above this second prominent shale-bed there is not so great a difference in thickness of consecutive shales and limestones, and correspondingly there is no particularly prominent escarpment line produced at the surface.

The prominent escarpments produced by these unusually heavy shale-beds may be observed by any one while riding across the country, and are so prominent features of the landscape they become appropriate means of subdividing the Coal Measures. The scheme of classification mentioned and illustrated in plate III has been worked out and is based upon conditions which actually exist and are prominent entirely across the state from north to south. It will be explained briefly here before taking up the several minor subdivisions for detailed description.

CHEROKEE STAGE.

At the bottom of the Coal Measures lie the Cherokee shales, with occasional calcareous lentilles and large masses of sandstones. These sandstones are the principal oil and gas producers. Their horizontal extent is not sufficiently great, neither is their occurrence sufficiently regular, to permit of a definite division of the shale-beds. It is proposed to speak of this entire complex as the Cherokee Stage. (See plate III.)

MARMATON STAGE.

Above the rocks of the Cherokee Stage we find a series of four limestone formations, alternating with as many shales. They are, reading from the bottom upwards, the Fort Scott limestone, Labette shales, Pawnee limestone, Bandara shales, Altamont limestone, Walnut shales, Coffeyville limestone, and Pleasanton shales. The four limestones with the three interbedded shales are relatively hard to distinguish by casual observation. The Fort Scott limestone caps a prominent scarp which distinguishes it from rocks in the Cherokee Stage, but, on account of the thinness of the interbedded shales, there are no direct surface features in connection with the other three limestones named. Above them we find the thick Pleasanton shales, which, in connection with the first limestone above, pro-

duces a more prominent scarp than the one at the top of the Cherokee shales. We include these four limestones and shales in one stage as they will fit the geography of the country admirably and assist in explaining the origin of the present surface features. Consequently, all the formations included with the Fort Scott limestone at the base and the Pleasanton shales on top are grouped together and named the Marmaton Stage, on account of the Marmaton river throughout almost its entire length having its channel within these different formations. Its upper streamlets rise practically on the top of the Pleasanton shales, and it just barely cuts through the Fort Scott limestone where it passes out of the state.

POTTAWATOMIE STAGE.

Above the rocks of the Marmaton Stage we have another complex, consisting of seven limestones along the southern part of the state and six interbedded shale-beds, which form a natural grouping, and are here segregated under the name of the Pottawatomie Stage. They are the Bethany Falls limestone, Ladore shales, Mound Valley limestone, Galesburg shales, Dennis limestone, Cherryvale shales, Drum limestone, Chanute shales, Iola limestone, Lane shales, Allen limestone, Vilas shales, and Stanton limestone. The name was chosen because the Pottawatomie river rises near the Stanton limestone, the uppermost one of the complex, and flows over the gently upturned edges of a number of the formations here included.

DOUGLAS STAGE.

Above the rocks of the Pottawatomie Stage is a heavy bed of shales separated by a thin limestone, the Kickapoo, the middle and southern end of which is so thin it has exercised no influence in determining surface features. The upper part of the Pottawatomie forms the most remarkable dip slope in the entire state. The soft overlying shales are worn away, leaving a zone from ten to twenty miles wide with the Stanton practically at the surface. This zone reaches from the south line of the state northeastward to the Missouri river near Leavenworth. At the western border of this dip zone is a prominent escarpment extending throughout the entire distance. The walls of the scarp are composed of the Lawrence shales capped with the Oread limestone. Here, again, we have a natural grouping of formations, consisting of the heavy

shale-beds and the overlying limestones which have produced the most prominent escarpment in the state. They are the Le Roy shales, Kickapoo limestone, Lawrence shales and Oread limestone.

SHAWNEE STAGE.

Immediately above the rocks of the Douglas Stage we find a complex of alternating limestone and shales, no one of which is particularly prominent, but each in the aggregate covers a zone reaching entirely across the state. Named from the bottom upwards, they are, Kanwaka shales, Lecompton limestone, Tecumseh shales, Deer Creek limestone, Calhoun shales, Topeka limestone, Severy shales, Howard limestone, Scranton shales. There is a limestone immediately under the Burlington which is thin and not persistent and therefore will only be mentioned as a part of a shale-bed in this Stage. In the southern part of the state the Howard limestone caps a prominent escarpment. The Burlingame limestone and the shales beneath produce a scarp traceable for one hundred and fifty miles.

The name Shawnee Stage is chosen on account of the great prominence of these rocks in Shawnee county, which contains the capital of the state. In the scheme here used, and in plate III, the classification of all the formations between the Burlingame limestone and the Permian is copied directly from Prosser.[7]

WABAUNSEE STAGE.

The name Wabaunsee is applied to the great complex of strata from the Burlingame limestone up to the Cottonwood limestone. It includes the Burlingame limestone, Olpe shales of Adams, Emporia limestone, Admire shales, Americus limestone, Elmdale formation, Neva limestone and Eskridge shales.

COUNCIL GROVE STAGE.

The Council Grove Stage includes the Alma or Cottonwood limestone, Florena shales, Neosho formations, and Garrison formation.

This completes the geological column throughout the Carboniferous. It is followed immediately by the Permian, for which Prosser will be quoted again.

7. Jour. Geol., vol. x, No. 7, 1902, p. 718.

Permian.

CHASE STAGE.

The Chase Stage includes the Wreford limestone, Matfield shales, Florence flint, Fort Riley limestone, Doyle shales and Winfield formations.

SUMNER STAGE.

The Sumner Stage includes the Marion formations and the Wellington shales. Here is the top of what originally was called the Permian. It is followed immediately by the so-called Red Beds, the exact geologic age of which was not known until within the last few years. Paleontological evidence has greatly accumulated, principally through the efforts of Cope, Williston, Gould and Beede, all of which implies that the Red Beds are Upper Permian in age. According to this the Permian may be divided into two series, as was done by Cragin in 1896. The lower one he named the Big Blue Series, including the Chase and Sumner Stages as just given. The upper one he named the Cimarron Series, divided into two Stages, from the bottom upwards, the Salt Fork Stage and the Kiger Stage.

SALT FORK STAGE.

This includes the Kingfisher formation, or Harper sandstone, and Salt Plain member; Glass Mountain formation, including Cedar Hill sandstone and Flower Pot shales; Cave Creek formation, including Medicine Lodge gypsum, Jenkins Clay and Shimer gypsum; Dog Creek formation, including Amphitheatre dolomite and Chapman dolomite.

KIGER STAGE.

This Stage includes the Red Buff formation, Day Creek dolomite, and Taloga formations.

Cherokee Shales.[8]

The name Cherokee shales was given by Haworth and Kirk in 1894 to a heavy bed of shales lying at the base of the Coal Measures in Kansas. The name was chosen on account of their prominence in Cherokee county, the southeastern county of the state.

Thickness.—The Cherokee shales are from 400 to 500 feet thick. They vary slightly from place to place, but on the whole are remarkably uniform. Some of the deep wells in the

8. Haworth and Kirk: Kan. Univ. Quart., vol. II, p. 105. Lawrence, 1894.

western part of the oil-fields imply a thickness of less than 400 feet, while others show more than 650 feet.

The well at Topeka passed entirely through them, but it shows 704 feet of shale at the bottom of the well. The McFarland well, although 2006 feet deep, seems to have penetrated the Cherokee shales nearly 174 feet, thus leaving us in doubt as to their total thickness at that place.

The Atchison diamond drill well went entirely through the Cherokee shales and into the Mississippian beyond. At that place they are 598 feet thick. Southward at Emporia is a well recently drilled by the city, under the immediate supervision of Alva J. Smith, who kindly furnished the Survey with a record. According to this record the Cherokee shales were reached at 1600 feet and the Mississippian limestone at 1951 feet, making them nearly 351 feet thick. Still further south, in the Osage and Cherokee territories, these shales begin to thicken and apparently grow thick very rapidly further south.

It would seem, therefore, that the Cherokee shales in general thicken to the north and northwest in the direction of Atchison and Topeka and become thinner westward towards Emporia and gradually grow thicker southward in the Cherokee and Osage country.

Area.—The Cherokee shales occupy the surface over nearly all of Cherokee county, the southwestern half of Crawford county and a small portion in the southeast corner of Labette county. The Marmaton river in Bourbon county has cut its valley through the overlying limestones and exposes them, as do also the upper waters of the Drywood in southeast Bourbon and northeast Crawford counties.

Beyond the limits of the state on the south the Cherokee shales are known to cover a wide area in the Cherokee Nation, and quite likely they appear eastward across into the coal-fields of Arkansas south of the Arkansas river. Mr. Taff[9] and assistants on the United States Geological Survey have demonstrated the existence of a heavy bed of shale in the Choctaw, Creek and Cherokee Nations which connects directly with the Arkansas coal-fields just mentioned. There is no reasonable doubt but that they are a southern extension of the Kansas Cherokee shales, although a short interval of space intervenes between the south line of the state and the areas mapped and

9. Taff, Joseph A.: Nineteenth An. Rep. U. S. G. S., pt. III, pp. 423-583. Washington, 1899.

it must be worked out before the connection is positively established.

To the north and northeast the Cherokee shales have been traced by the writers across into Missouri as far north as the north side of Bates county, and indirectly, by a careful study of well records which have been referred to us on different occasions by well-drillers, they have been traced as far northeast as the Missouri river. We may say, therefore, that from our own personal knowledge they extend northeastward to the Missouri river. Missouri geologists in various reports, and Iowa geologists in practically all reports published which bear on the subject, have shown conclusively that the same shale-beds extend northward from the Missouri river across the remainder of Missouri and into the coal-fields of Iowa as far north as the Iowa coal-fields have been traced. This makes a continuous bed of Cherokee shales extending from the coal-fields of Arkansas south of the Arkansas river northward to the central portion of Iowa.

Character.—In character the Cherokee shales vary materially, both vertically and longitudinally. In color some of them are a light ashen gray, from which they pass by gradual stages into jet-black bituminous shales. In material they vary from the finest-grained clay shales into arenaceous shales and finally into sandstones. Much of the soil produced from them where they occupy the surface is light-ashen in color, due largely to a lack of organic matter in the shales themselves. Elsewhere the soil is a rich black on account of the amount of bituminous material in the shales.

Limestone in the Cherokee Shales.—In many places small and irregular lentilles of limestone are found within the shales, occasionally with a lateral extent of a number of miles. The most prominent of these is a limestone found a short distance below the surface at Cherokee, which is exposed along the upper branches of Cherryvale creek northwest of Cherokee and again north of the Marmaton river near the east line of the state, where it appears at the surface and causes considerable annoyance to the farmers by its frequency in the fields. Here it breaks up into angular blocks, the so-called "diamond rock" of the farmer.

In addition to this other small beds are noted, and partly irregularly shaped calcareous concretionary masses which are found with considerable frequency, and yet irregularly. Fig-

ure 1 is a reproduction of a diagrammatic section at Fort Scott prepared by Mr. Bennett and published as figure 4 in volume I and as figure 1 in volume III of this series of reports. At Fort Scott and elsewhere there is also a tendency to produce spheroidal and ellipsoidal concretionary masses, some of which are more than two feet in diameter. They are largely calcareous in composition, but contain so much clay and organic matter that the calcareous nature is partially concealed.

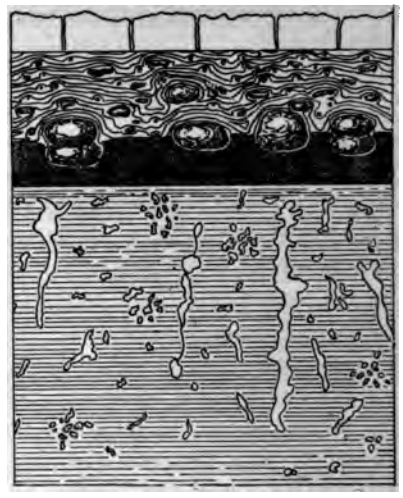


Fig. 1. Section at Fort Scott in the shale adjacent to the Fort Scott coal. (After Bennett's fig. 4, vol. I.)

Fossils are fairly abundant in the vicinity of such concretions and particularly so in the limestone beds above mentioned.

Sandstones in the Cherokee Shales.—Sandstones are very abundant here and there throughout the Cherokee shales. For years efforts have been made to find one or more sandstone beds of sufficient persistency to become valuable for stratigraphic studies. Where we can find them exposed at the surface this is possible in part. For example, the sandstone on top of the hills in the vicinity of Crestline and Timbered Hills, in Cherokee county, has a lateral extent of eight to ten miles. But it gradually disappears and so has "no beginning and no ending." At other places in the Cherokee shales sandstone is very abundant and some of the finest flagging stones in the state come from this vicinity. Sandstones have a great vertical range, some of them being near the top of the shales, near the middle, and others nearer at the bottom, with an occasional bed of coarse sandstone immediately overlying the Mississippian.

By far the greater part of all oil and gas produced in the state comes from the sandstones in the Cherokee shales. Well-drilling in the oil-fields shows a variation analogous to that found further east where the shales come to the surface. Oc-

casionally a well will pass entirely through the Cherokee shales without finding any sandstone. Elsewhere the productive sand is from 50 to 100 feet in thickness and lies at various elevations within the Cherokee shales. The detailed discussion of sandstone is reserved for another chapter, in discussing the occurrence of oil. It may be stated here, therefore, that the principal cause for the spotted character of the oil-fields is irregularity in occurrence of the sandstones.

Coal in the Cherokee Shales.—The Cherokee shales contain large quantities of coal, which is scattered through the shales in a manner similar to that just given for sandstone. The coal mined in Cherokee, Crawford, Leavenworth and Atchison counties all comes from the Cherokee shales. Years ago Atchison produced a small amount of coal from the Lawrence shales, which should not be confused with the coal now produced from the deep mines at that place. Well-drilling has shown us that coal is irregularly scattered through these shales farther to the west. For example, a 28-inch bed of it lies just above the Mississippi limestone under Cherryvale. At other places in Montgomery county drillers report a bed of coal 4 to 5 feet in thickness. Similar reports come from a number of other places, showing that the Cherokee shales in the aggregate are exceedingly rich in carbon.

For list of fauna of the Cherokee shales see chart, plate XLII; for list of flora see chapter by Doctor Sellards, this volume.

Fort Scott Limestone.[10]

The name Fort Scott limestone is here applied to the two limestone beds occurring at Fort Scott with about 7 feet of shale between, which beds have been traced in detail both southwest and northeast to beyond the state line, as represented on the map given as plates I*a*, I*b* and I*c* and in the various geological sections, plates III and IV.

In 1894 Haworth and Kirk,[11] in a preliminary description of a geological section along the Neosho river, named these rocks Oswego limestone, which name was retained in volume III of this series of reports. In his report on Kansas geology in 1866 Swallow named the upper one the Fort Scott limestone. Since the first publication of the name Oswego, in 1894, it has been

10. Swallow, Prof. G. C.: Rep. Kan. State Geol. Surv., p. 25. Lawrence, 1866.

11. Haworth, Erasmus, and Kirk, M. Z.: Kan. Univ. Quart., vol. II, p. 105. Lawrence, January, 1894.

learned that the name was previously occupied, as Prosser* had used it in connection with a division of the Silurian in the state of New York.

As the name Fort Scott is just as appropriate on account of the rocks being so well exposed in the environs of the city by that name, and partly on account of Swallow having proposed the name for the upper bed, the term is here adopted to replace the name Oswego previously used by this Survey.

Thickness.—The Fort Scott limestone consists of two members, an upper and lower, which are separated by a thin but persistent shale-bed from 7 to 8 feet in thickness. The upper member averages from 10 to 12 feet in thickness, and is quite uniform in character and thickness wherever found in the state. The lower member is from 5 to 6 feet thick at Fort Scott and reaches a thickness of 18 feet at Girard, as shown by the well records at that place, and is quite variable in character wherever observed. The upper member is divided into different layers, so that it is well stratified wherever found. The lower one consists of one layer only at Fort Scott, is quite impure, and on that account is used for making hydraulic or natural cement. For a more detailed account, reference should be made to page 40, volume I, of this series of reports.

Area.—The Fort Scott limestone covers a narrow band or zone from the south side of the state, near Chetopa and Oswego, northeastward to the east state line in the vicinity of Fort Scott and Fulton. In places there is a marked dip slope on the top of the limestone from which the overlying formations have been eroded a number of miles back to the west. Elsewhere the zone narrows by the overlying limestone approaching the eastern limits of the Fort Scott limestone. Reference should be made in this connection to the general areal map, plate VII*a*, VII*b*, VII*c*.

Fauna of the Fort Scott Limestone.—For list of fossils from the Fort Scott limestone see Doctor Beede's chart, plate XLII.

Labette Shales.[12]

The name Labette shales is applied to a bed of shales lying immediately above the Fort Scott limestone. The term was

* Prosser, Prof. Chas. S.: Bul. Geol. Soc. Amer., vol. IV, pp. 100, 108, 116, 1892.

12. Haworth, Prof. E.: Univ. Geol. Surv. of Kan., vol. III, p. 100. Lawrence, 1898.

first used in volume III, page 36, of this series of reports, suggested by Adams while the manuscript was in preparation. Previously Haworth and Kirk[13] had suggested the name Laneville shales in their preliminary report on the geological section along the Neosho river. Later the term Laneville was dropped when the formations named in the section made in 1894 were first correlated, as explained earlier in these pages.

Thickness.—The Labette shales vary from 20 to 60 feet in thickness. On the north side of the Marmaton river near Fort Scott they are not more than 20 feet thick. West of Fort Scott from two to three miles they measure fully 60 feet in thickness. These extremes are the greatest variations observed anywhere in the state.

Area.—The Labette shales cover a narrow zone or belt lying within the outcropping lines of the overlying Pawnee and the underlying Fort Scott limestone. It is rarely more than a few miles in width and in some places narrows to a few yards. Its position in a northeast-southwest line is well represented on the surface map, plate VII*a*, VII*b* and VII*c*.

Fauna.—The Labette shales have numerous calcareous concretions and streaks and a good supply of invertebrate fossils associated with them. For a complete list see Doctor Beede's chart, plate XLII.

Pawnee Limestone.[14]

The name Pawnee limestone was given by Professor Swallow to the limestone first overlying the Labette shales, largely developed along Pawnee creek in Bourbon county.

Thickness.—The Pawnee limestone is from 8 to 52 feet in thickness, the thinner places being undoubtedly where the upper part has been worn away by erosive processes. However, it is a limestone which varies in thickness from place to place more than some of the other Kansas limestones.

Area.—The Pawnee limestone is exposed along a narrow zone from the south line of the state west of Chetopa to the east line of the state in the vicinity of Fulton, as shown on the accompanying map. It does not cover a very wide surface, probably two miles representing the greatest space from which the overlying shales have been washed away. At different

13. Kan. Univ. Quart., vol. II, p. 108. Lawrence, January, 1894.

14. Swallow, Prof. G. C.: Geology of Kansas, p. 24, section No. 203. Lawrence, 1866.

places in Bourbon and Linn counties streams have cut away the shale to its surface, making its exposure along the stream two or three times the distance given.

Characteristics.—The Pawnee limestone differs so radically in general physical characteristics from the underlying Fort Scott limestone that the two may be distinguished quite readily. First, it is not divided into thin beds or layers very regularly; second, it is much more massive in appearance, and produces as a result large boulders; third, it is much more ferruginous than the Fort Scott limestone, so much so, indeed, that the soils formed in connection with it generally have a reddish iron-rusty color.

Fauna.—The Pawnee limestone is not so fossiliferous as some of the others, particularly the Fort Scott. It is well supplied, however, and the reader is referred to the chart by Doctor Beede, plate XLII, for a complete list.

Bandera Shales.[15]

The name Bandera shales is here applied to the shale-bed lying above the Pawnee limestone and below the Altamont. This is the shale-bed called the Lower Pleasanton shale in volume III, page 40, of this series of reports, published in 1898.

Thickness.—The Bandera shales vary in thickness from 60 to 100 feet. They are comparatively uniform in character and thickness but sometimes change very suddenly lithologically.

Area.—The Bandera shales occupy a narrow zone reaching from the south side of the state in the vicinity of Altamont northeastward to the vicinity of Prescott along the east side of the state. They occupy a zone from three to eight miles in width, which is quite uniform in direction from the south line of the state northeastward to the vicinity of Erie, in Neosho county. From here northeastward it becomes very irregular, due to the irregular surface topography. In its northeastern extension in the southern part of Labette county it is particularly narrow and serpentine-like in direction. Beyond Fort Scott it becomes more regular, and passes out of the state northeast of Prescott.

Characteristics.—The Bandera shales are principally noted for their arenaceous qualities, which frequently reach extreme degrees, producing most beautiful sand flagging stones. They vary in quality from an arenaceous shale to a shaly sandstone,

15. Adams, Dr. George I.: U. S. G. S., Bull. No. 211, p. 32. 1903.

rarely being a pure sandstone. Extensive quarries of valuable flagstones have been opened up in many places, the most notable being in the vicinity of Farlington, Bandera, Gilfillan, Redfield and Pawnee. Their arenaceous character is observable farther west where reached by the drill, and a number of excellent gas-wells and oil-wells obtain their product from the sandstones in the Bandera shales. In places their change from sandstones to clay shales is very rapid and hence remarkable. They also carry considerable coal, which in places becomes workable, such as the coal-mines near Hammond, Fulton and Prescott, that have been worked to a considerable extent.

Altamont Limestone.[16]

The name Altamont limestone is here applied to the limestone at Altamont, the schoolhouse at that place being built immediately on top of it. This name was first used by Adams in volume I of this series of reports. It is also described by Bennett[17] in volume I of these same reports, being spoken of as the "8-foot system" lying within the Pleasanton shales, showing that at that time it was sufficiently persistent to be recognized as dividing the Pleasanton shales.

Later, Adams[18] withdrew the name Altamont and substituted the name Parsons for the same formation. In his later description he speaks of it as consisting of two members. Subsequent work by this Survey has shown conclusively that he was in error, and that the upper limestone is the one so prominent at Coffeyville which is designated the Coffeyville limestone later in this volume. Why he should have changed the name Altamont to Parsons with no apparent reason is entirely unknown. As Altamont has already appeared in volume I of this series of reports, of course we are under the necessity of retaining the name, and this is particularly desirable on account of its eminent appropriateness.

Thickness.—The Altamont limestone is nowhere more than 10 feet thick, from which it decreases in places to a thickness of from 3 to 4 feet.

Area.—The Altamont limestone occupies a zone extending from the south side of the state opposite Altamont northeastward to the east side of the state in the vicinity of Pleasanton.

16. Adams, Dr. George I.: Kan. Univ. Geol. Surv., vol. I, p. 22. Lawrence, 1896.

17. Bennett, Rev. John: Kan. Univ. Geol. Surv., vol. I, p. 94. Lawrence, 1896.

18. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 33. Washington, 1903.

It caps a comparatively prominent escarpment in places, such as Altamont, Edna on the south and Hammond on the north.

Characteristics.—The Altamont limestone has no specially marked characteristics which particularly distinguish it from other limestones in this part of the state. It furnishes stone for quarrying purposes at Parsons and fairly good quarries could be opened at other places. Throughout a part of its course it is practically one solid mass of limestone, but elsewhere is divided into individual layers permitting it to be quarried regularly.

For list of fauna of the Altamont limestone, see chart, plate XLII; for list of flora, see chapters by Doctor Sellards, this volume.

Walnut Shales.

The name Walnut shales, here used for the first time, is applied to the bed of shales filling the interval between the Altamont and Coffeyville limestones. They are clay shales, differing so little in color and general characteristics from other shales in this part of the state that from physical properties alone there is nothing specially to designate them. They cover a narrow strip from Pleasanton southwest by way of Parsons, throughout which distance they are about a mile in width. From here southwest they gradually widen until in the vicinity of Edna they are from six to eight miles in width. They cover the surface around the town of Walnut, from whence the name is taken.

Walnut Shales.

The name Dudley shales was applied by Adams to a bed of shales described as follows: "The name Dudley shales is here applied to the beds occupying the interval between the Parsons limestone and the Hertha limestone, which, as explained above, in the discussion of the synonym, are the equivalent of Haworth's Lower Pleasanton shales." We apply the name Walnut for a portion covered by Adams's name Dudley, for the following reasons: First, the town of Dudley does not rest on these shales at all, but on the Ladore shales named by Adams, which name we adopt and which lie above the Bethany Falls limestone. Second, Adams, under the name Bandera shales, says, page 32: "These shales are the equivalent of the Lower Pleasanton shales of Haworth." This latter state-

19. Adams, Dr. Geo. I.: U. S. G. S., Bull. 211, p. 34. Washington, 1903. Also Bull. 238, p. 17. Washington, 1904.

ment is correct, making the statement that the Dudley shales correspond to Haworth's Lower Pleasanton shales impossible. Third, we want a name for the shale-beds above the Altamont limestone and below the Coffeyville limestone, but Adams did not recognize the Coffeyville limestone, so spread the name from the Altamont to the Bethany Falls limestone, thereby crowding out Haworth's[20] Lower Pleasanton shales, which, by all the laws of priority, should be retained. The name Walnut shales, therefore, is applied by us to the shales above the Altamont limestone and below the Coffeyville limestone.

Coffeyville Limestone.

The name Coffeyville limestone is here used for the first time. It is applied to the limestone so prominent at Coffeyville, from which place it takes its name. It is the limestone spoken of as a member of the Parsons by Adams.[21] Adams's error was due to a lack of detailed information. Since his latest publication on the subject this limestone has been traced with great detail by Bennett, who has been able to determine without question that it is a separate limestone formation extending entirely across the corner of the state. Its independent existence warrants us in giving it a distinct name.

Thickness.—The Coffeyville limestone varies from 2 to 3 feet in thinnest places to a maximum of 10 or more feet where it is thickest. From the vicinity of Mound Valley south it averages 8 to 10 feet.

Area.—The Coffeyville limestone is prominently exposed along both sides of the Verdigris river at the south line of the state and at Coffeyville. It covers but a narrow zone on account of the overlying shales not being entirely removed by erosion. To the northeastward, in Labette county, it occupies a wider zone, which in some places is from seven to eight miles wide along Pumpkin creek and its tributaries. Farther northeast the limestone grows thinner and consequently has had a less influence in shaping surface features. As a result it is visible only in places, but sufficiently so to warrant a belief that it is entirely continuous to the northeast beyond the state line. As the underlying shale-beds separating it from the Altamont limestone grow thinner to the north, the outcropping of the Coffeyville limestone correspondingly appears more nearly along the same lines with the Altamont.

20. Haworth, Prof. E.: Kan. Univ. Quart., vol. III, p. 274. Lawrence, 1895.

21. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 33. Washington, 1904.

Fauna.—See Doctor Beede's chart, plate XLII.

Pleasanton Shales.[22]

The term Pleasanton shales was first introduced by Haworth in 1895. At that time it was applied to the entire mass of shales lying above the Pawnee limestones and what was then called the Erie limestone, the lower member of which is now known to be the Bethany Falls limestone. The intervening Altamont and Coffeyville limestones were not known at that time. Later, in volume I of this series, in his section west from Fort Scott Bennett[23] referred to the Altamont and Coffeyville limestones, but still they were not recognized as having any considerable lateral extent. Still later, in volume III, Haworth[24] recognized the Altamont limestone as being prominent in the southern part of the state, but was of the opinion it did not extend much north of Fort Scott. He therefore speaks of the Lower Pleasanton shales and the Upper Pleasanton shales for the southern part of the state, and described those two beds as coalescing into one north of Fort Scott. It is now known, however, that the Altamont and Coffeyville limestones are continuous entirely across the state, this knowledge having been acquired by field-work during the summer of 1905. It is desirable, therefore, to give individual names to each interbedded shale formation. Consequently the name Pleasanton shales is reserved and here applied to the upper portion, which is by far the heavier and more prominent, and the names Bandera and Walnut are applied to the others, as already shown in previous pages.

It should be noted that Professor Swallow, in his report for 1866, gave no name for either of these shale-beds, and as best we can determine by a careful study of his report they correspond to the lower part of his Marais des Cygnes Coal Series, probably from his numbers 188 to 192, inclusive, but it must be confessed we are somewhat in doubt on this subject.

Thickness.—The Pleasanton shales as here described have a general thickness of 125 to 150 feet. Their greatest thickness is in the vicinity of Blue Mound, Boicourt and La Cygne, where they constitute the main mass of the high hills, which are capped with overlying limestones.

Area.—The Pleasanton shales occupy a zone noted for its

22. Haworth, Prof. E.: Kan. Univ. Quart., vol. III, p. 274. Lawrence, 1895.

23. Bennett, Rev. John: Kan. Univ. Geol. Surv., vol. I, pp. 94, 95. 1896.

24. Haworth, Prof. E.: Univ. Geol. Surv. of Kan., vol. III, pp. 39-43.

prominent escarpments, stretching from a few miles north of the south line of the state and passing across the east line to the east and southeast of La Cygne. They are readily recognized throughout this entire distance, as they form the main mass of the hills from the water reservoirs at Coffeyville northeast throughout the entire distance named. At Pleasanton the schoolhouse hill, capped with the Bethany Falls limestone, is composed principally of the Pleasanton shales. To the east and southeast of this prominent line of escarpment they occupy the low ground at the outcropping of the Coffeyville limestone already given.

Characteristics.—The Pleasanton shales are quite variable in character at different places and at different levels. They contain large numbers of calcareous lentilles and concretionary masses, and also here and there have fairly well-bedded sandstone layers. Just north of Pleasanton this sandstone is so well developed that it is extensively quarried for the markets.

Oil and Gas in Pleasanton Shales.—These shales also are comparatively productive of oil and gas. They furnish these products at Rantoul, Paola, and a number of places to the west.

Fauna.—See Doctor Beede's chart, plate XLII.

Bethany Falls Limestone.[25]

The name Bronson limestone was used by Adams to designate the combination or assemblage of three distinct limestone formations which are definitely marked in the southern part of the state, but which come close together on the north by the thinning of the interbedded shales, so that from the middle of eastern Allen county northeastward they produce but one escarpment. These limestones have caused more discussion and confusion in the use of names than any other formation in the state. In his report in 1866 Swallow confounded them with a number of overlying limestone formations, called them in places the Well Rock Series, and again the Spring Rock Series, and again included them in his Marais des Cygnes Coal Series.

When this Survey first began investigations Bennett[26] ran a geological section west from Fort Scott and encountered these three limestones in the prominent escarpments near Uniontown. He recognized two shale partings, and therefore spoke of the limestones as forming a "triple system," which term was

25. Adams, Dr. George I.: U. S. G. S., Bull. 238, p. 17. Washington, 1904.

26. Bennett, Rev. John: Univ. Geol. Surv., vol. I, p. 95. Lawrence, 1896.

used by him provisionally in volume I because exact correlations were not definitely known. Later, Haworth and Kirk[27] named them the Erie limestone, on account of their prominent development to the northwest of Erie. Still later Adams gave names to the three individual limestone formations as they occur to the south, and, as above stated, suggested the name Bronson limestone for their combination on the north, inasmuch as the name Erie was previously occupied.

In 1872 Broadhead[28] gave the name Bethany Falls limestone to a limestone formation which in his general section is numbered 78, and described it as occurring on the south bank of the Missouri river at the end of the Hannibal bridge, Kansas City, and at a number of places in the north part of the state. The abutment at the south end of the Hannibal bridge rests directly on this limestone, and the Missouri Pacific tracks between the bridge abutment and the river also rest on the upper surface of this limestone.

Keyes[29] suggested that the name Bethany limestone be applied for quite a series of rocks occurring northward in Missouri and Iowa, but has never been able to give a definite description of them. Consequently we cannot use the term here as he used it for the reason that we do not know to what extent he wished it applied.

Recent investigations by this Survey have demonstrated conclusively that the Bethany Falls limestone of Broadhead, his number 78, is the lower member of Adams's Bronson limestone, of the "triple system" of Bennett, and of the Erie limestone of Haworth and Kirk. Priority requires, therefore, that the term Bethany Falls be used to designate this lower limestone formation. It will, therefore, replace the name Hertha limestone of Adams,[30] which term, by Adams's recommendation, has in general been accepted by the United States Geological Survey and used in their Bulletin 238, page 18.

Thickness.—The Bethany Falls limestone is described originally in the Uniontown section by Bennett as 22 feet thick. Southward it gradually grows thinner until it gradually disappears in the vicinity of Mound Valley. To the northeast,

27. Haworth and Kirk: Kan. Univ. Quart., vol. II, p. 108. Lawrence, 1894.

28. Broadhead, Dr. G. C.: Mo. Geol. Surv. Rep., 1872, pp. 76, 77, 79, 80, 97, 167, 203.

29. Keyes, Dr. C. R.: Mo. Geol. Surv., vol. X, p. 45, *et seq.*

30. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 35. Washington, 1903.

where it is so closely associated with the Mound Valley and Dennis limestones, it retains its thickness and is fully 20 feet thick at Graystone Heights, Kansas City, where it is exposed along the bluffs of Turkey creek and is given at 20 feet 8 inches by Broadhead in his general section.

Area.—The Bethany Falls limestone appears just west of Mound Valley not much above a level with the streets of the town. South of this it has not been seen. Here it is little more than 12 inches in thickness. Its outcropping line from here to the northeast parallels that of the Coffeyville limestone beneath it and the Mound Valley limestone above it. It occurs on the low hills a little east of Erie, and some fifteen to twenty miles north its outcropping line becomes the same as the general escarpment capped by the Bethany Falls, Mound Valley and Dennis limestones. From this area the outcropping lines of the three continue northward, forming an exceedingly irregular or zigzag line covering a zone from fifteen to twenty miles in width, and passes across the east line of the state into Missouri in the southeast part of Miami county. From here it swings to the east an unknown distance, but passes back westward along the Missouri river, entering the state in the bluffs on both sides of the Kansas river at Kansas City, up which stream it extends almost to Holliday. It also extends up the west side of the Missouri river almost to Quindaro.

Characteristics.—The Bethany Falls limestone in general may be characterized as moderately pure in composition, ranging from 90 to 95 per cent. calcium carbonate, thick bedded, almost pseudomassive in places, and resisting the influence of weathering agents more than the ordinary limestone. It bleaches to more nearly a pure white than any of the limestones described lying beneath it. Its walls and blocks along the line of its outcropping present a beautiful white appearance in the distance.

Fauna.—See Doctor Beede's chart, plate XLII.

Ladore Shales.[31]

The name Ladore shales was used by Adams to designate the shales lying between the Bethany Falls limestone below and the Mound Valley above. It is here used with that significance.

31. Adams, Dr. George I.: U. S. G. S., Bull. 238, map plate 1, p. 14. Washington, 1904.

Thickness.—The Ladore shales have their greatest thickness in the southern part of the state, where they reach a maximum of 40 feet. Northeastward they gradually grow thinner, permitting the two enclosing limestones to come closer and closer together until in the vicinity of Uniontown the shales have a thickness of from 7 to 10 feet. To the northeast of this they continue to grow thinner until at Kansas City and Turner they are only about 3 feet thick. On the extreme south, beyond the limits of the Bethany Falls limestone, they coalesce with the Pleasanton shales, which underlie the Bethany Falls limestone.

Character.—In general the Ladore shales are ordinary clay shales about the average of those found elsewhere in the Carboniferous of the state.

Mound Valley Limestone.[32]

The name Mound Valley limestone was used by this Survey in volume I of this series of reports at the suggestion of Doctor Adams, who at that time was one of the field assistants. Later Adams[33] abandoned this name and introduced in its stead the name Dennis limestone, without giving any reason for so doing. His writings, however, show that he confounded the Mound Valley limestone with the one first above; or, rather, he recognized only three of the four limestones occurring here and therefore dropped one name. This Survey still uses the name Mound Valley, as it did originally, to designate the limestone on the hills immediately northwest of Mound Valley.

Thickness.—The Mound Valley limestone is 3 or 4 feet thick at Mound Valley and gradually grows thinner to the southwest until it disappears. To the northeast of Mound Valley its thickness increases to Uniontown, where it is 16 feet thick. From here northward it decreases, and is about 6 feet at Kansas City.

Area.—The Mound Valley limestone does not extend as far south as the state line, but gradually grows thinner until it disappears about ten miles north of the state line, one or two miles east of the Verdigris river. To the northeast it is coextensive with the Bethany Falls limestone, as already explained, and does its part in the formation of the bluff line and scarp line already described.

32. Adams, Dr. George I.: Univ. Geol. Surv. of Kan., vol. I, p. 23. Lawrence. 1896.

33. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 36. Washington, 1903.

Characteristics.—The Mound Valley limestone in all of its essential properties is about the same as the Bethany Falls limestone already described. The two are so similar that one would be unsafe in trying to distinguish the difference between them by mere physical properties.

Fauna.—See Doctor Beede's chart, plate XLII.

Galesburg Shales.[34]

The name Galesburg shales was proposed by Adams to designate, as he put it, "the rocks occupying the interval between the Hertha limestone and the Dennis limestone." As has already been shown, Adams in some way overlooked the existence of the Mound Valley limestone, which separates the shale-bed he referred to into two parts. For the shales below the Mound Valley limestone we have already accepted Schrader's name, Ladore shales. It is here proposed to retain the name Galesburg shales for those lying above the Mound Valley limestone and below the Dennis limestone.

Thickness.—In the southern part of the state these shales reach a maximum thickness of fully 60 feet along the bluff lines of Big creek in northwestern Labette county. To the northeast they gradually grow thinner. West of Uniontown two miles they are about 8 feet thick, and at Kansas City they are not more than 5 or 6 feet in thickness.

Area.—The area occupied by the Galesburg shales necessarily is triangular in outline, with the widest part towards the south. On account of the peculiar topographic properties of the surface at no place do they cover a wide stretch of surface, but are known principally in the bluff lines and scarp walls. From the vicinity of Uniontown northward they are known only as the parting walls between the thin beds of limestone.

Characteristics.—The Galesburg shales have no distinguishing characteristics. They are practically the same as the Ladore shales and others in this part of the state. They are clay shales to a great extent, here and there changing to arenaceous and bituminous.

Dennis Limestone.[35]

Adams used the name Dennis limestone to designate a limestone formation immediately underlying the little way station

34. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 36. Washington, 1903.

35. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 36. Washington, 1903.

on the railroad between Parsons and Cherryvale. As explained above, he confounded these with the Mound Valley limestone, so that, so far as his writings are concerned, the name is equally applicable to each formation. As the name Mound Valley had already been used by this Survey it was retained with its original significance, and the term Dennis, out of courtesy to Adams, is now used for the upper one of the two to which he applied it.

Thickness.—The Dennis limestone constitutes the uppermost member of the old "triple system" limestone of Bennett and the Erie limestone of Haworth and Kirk. Opposite Uniontown it is fully 25 feet thick. Southward it gradually grows thinner to where it disappears along the Verdigris river. Northeastward it retains its thickness much better all the way to Kansas City, where it is about 10 feet thick in the bluffs along Turkey creek and at the Kansas river.

Area.—The Dennis limestone is almost exactly coextensive with the Mound Valley already described. Its outcropping is a little to the west. It underlies the town of Cherryvale, where it is found about 5 or 6 feet beneath the surface. The same may be said of it at the railroad station Dennis. Farther northeast an escarpment gradually appears with the Dennis limestone capping it. This escarpment becomes quite noticeable between Erie and Shaw. To the northeast of this area from ten to fifteen miles its escarpment gradually grades into that capped by the Mound Valley limestone until they unite southwest of Uniontown, as already explained.

Characteristics.—The Dennis limestone is practically identical in physical properties with the Mound Valley and the Bethany Falls already described. In some places it produces a cross-bedded structure, perhaps more than either of the other two. Near its upper surface it is well filled with cherty concretionary masses of irregular shapes and sizes, these cherts being mainly blue at the north but light-colored at the south. Along the wagon roads east of Bronson, where water has liberated the chert nodules, they have accumulated on the surface in great abundance, the larger ones being used by the farmers to weight down fence-posts. Some of them reach a maximum size of three feet in diameter and 300 pounds or more in weight. As a result of this unusual amount of chert there is a tolerably well-formed gravel-bed here and there over the surface for many miles in a northeast-southwest di-

rection along a zone where water has dissolved away the upper part of the limestone, thereby liberating the chert concretions. These gravel-beds have worked their way eastward for ten or more miles, or, most likely, are residues in areas from which the limestone has been entirely removed.

Fauna.—See Doctor Beede's chart, plate XLII.

Cherryvale Shales.[36]

The name Cherryvale shales is here used to designate the shale-bed with the Dennis limestone lying below and the Drum limestone lying above.

Thickness.—The Cherryvale shales in the vicinity of Cherryvale are from 50 to 125 feet in thickness. They reach their maximum thickness in the vicinity of Cherryvale and immediately to the north, where they constitute the main mass of the mounds and hills, such as the mound south of town where the brick-yards are established, the mound to the northwest where the other brick-yard is located, and the famous Bender mound, about eight miles out from Cherryvale. To the southeast they extend down as far as Coffeyville and beyond and form the principal part of the hill on which the Coffeyville water reservoir rests. It should be stated, however, that inasmuch as the Dennis limestone, Mound Valley limestone and Bethany Falls limestone gradually disappears southward, and neither of them reaches the south line of the state, all of the interbedded shales and also these Cherryvale shales coalesce with the Pleasanton shales immediately under.

It is probable that the upper part of the shale-beds in the Coffeyville mound were formed long after the Pleasanton shales ceased their growth; indeed, it is practically certain that the uppermost part was formed subsequent to the formation of the Dennis limestone. To the northeast they maintain their thickness quite well by way of Urbana and Blue Mound and probably reach all the way to Kansas City, but their thickness is greatly reduced.

Characteristics.—In the vicinity of Coffeyville the Cherryvale shales are emphatically arenaceous, but at Cherryvale they have lost this arenaceous property and have become a good grade of clay shales admirably suited for brickmaking and extensively used by the factories at that place. Farther

36. Haworth, Prof. Erasmus: Univ. Geol. Surv. of Kan., vol. III, p. 47. Lawrence, 1898.

to the northeast they have no specially characteristic properties.

Drum Limestone.[37]

The name Drum limestone was first suggested by Adams to designate the limestone covering the hilltops around Cherryvale and occurring in such abundance in the vicinity of Independence. Previously Haworth and Piatt[38] had applied the name Independence limestone to this same formation. It appears, however, that the name Independence was previously used by Calvin[39] for a division of the Devonian shales in the vicinity of Independence, Iowa, and its use must, therefore, be abandoned by this Survey.

Thickness.—The Drum limestone is the most variable in thickness of any one known in southeastern Kansas. On top of the bluffs south of Cherryvale it is only 5 feet thick, and still thinner to the north, but its thickness has been somewhat reduced by surface erosion. To the southwest its thickness increases very rapidly until at the Western States Portland Cement plant site just beyond Independence city limits to the southeast it has a thickness of about 80 feet. From here southward it rapidly decreases again and is not more than 6 or 8 feet in thickness on the Coffeyville hill at the Coffeyville water-works. North from Cherryvale it grows thinner and becomes a mere trace in the shales and sandstones east of Chanute. It has not been traced regularly farther north, but it has been observed in different places in Linn county and probably is the equivalent of one of the limestones on the bluffs at Kansas City. Doctor Beede says that "faunally it agrees with the Oolite of Kansas City."

Characteristics.—The Drum limestone at Independence has a high degree of purity and yields from 90 to 95 per cent. calcium carbonate upon analysis. Southward at the Coffeyville water-works it is exceedingly impure, one analysis giving only 78 per cent. calcium carbonate.

The plant at Independence makes a superior quality of Portland cement by using about four parts of the limestone to one of river-valley soil. To the northeast from Independence its properties do not greatly vary until the vicinity of Chanute is

37. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 37. Washington, 1903.

38. Haworth, Prof. Erasmus, and Platt, W. H. H.: Kan. Univ. Quart., vol. II, p. 115. Lawrence, 1894.

39. Calvin, Prof. Samuel: Amer. Jour. Sci. (3), vol. XV, p. 460. 1878.

reached, where it is quite thin and again becomes a very impure limestone largely mixed with clay shales material.

Fauna.—See Doctor Beede's chart, plate XLII.

Chanute Shales.[40]

The term Chanute shales is here used to designate the shale-bed lying first above the Drum limestone and first below the Iola limestone. This name was introduced by Haworth and Kirk in 1894 in a preliminary publication, as already explained in this report, at a time when a number of geological sections were run across the state. In that instance local names were given to each formation under each section. Later, when a system of correlation was introduced, some of these names had to be dropped. It was found that the name Chanute shales was applied to the same formation in one section that the name Thayer shales was applied to in another. In volume III of this series of reports, page 49, it was decided to drop the term Chanute shales and retain the term Thayer shales. As they had been introduced at the same time one of them necessarily had to be dropped and priority in no way entered into the question.

Subsequently Adams,[41] in a government publication, restored the name Chanute shales, apparently under the impression that priority demanded it, and the term has been used since then by at least two different governmental publications. At present, therefore, we are forced to decide between the use of the term Chanute, as employed by our government upon the advice of Adams, or Thayer, as previously employed by this Survey. As just explained, it is not a question of priority, the two being introduced at the same time and in a similar manner. The frequency of usage, however, is in favor of the government publications, and we bow, therefore, to the greater power and use the name Chanute. It may be stated in passing that possibly the shale-bed is the same as Broadhead's number 97, which he does not name, and that apparently it corresponds in part to what Swallow, in his 1866 report, calls Einstein sandstone No. 157. Why he should call so heavy a shale-bed a sandstone is not known, and also it should be remembered that the correlations were so imperfect that it is quite possible the above statement of Swallow is incorrect.

40. Haworth, Prof. Erasmus, and Kirk, M. Z.: Kan. Univ. Quart., vol. II, p. 109. Lawrence, 1894.

41. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 38. Washington, 1903.

Thickness.—The Chanute shales vary in thickness from 25 feet to 100 feet. Their greatest thickness is on the south where apparently they coalesce with the shales above, as will be explained in discussing the Iola limestone. To the northeast they gradually decrease in thickness, reaching a total of about 25 feet at Kansas City, where they are well exposed in the bluffs along the Missouri river, Turkey creek and the Kansas river.

Area.—The Chanute shales cover a zone wide at the south and growing narrow to the north. In the vicinity of Chanute, Urbana and Neodesha this zone is about nine miles wide, while at Kansas City it is a mere line in the almost vertical bluff. Its location can be seen at a glance on the surface map, VII*a*, VII*b* and VII*c*, and on the county maps for Neosho, Allen, Wilson and Montgomery counties, herewith included, where it occupies a space between the two enclosing limestones.

Characteristics.—The Chanute shales are exceedingly variable in character. Around Chanute they are a fine clay shale, excellently adapted for making brick, tile and pottery. Just east of the Neosho river, at Chanute, a sandstone appears which constitutes the main mass of the hills and is the exact equivalent of the clay shales only a few miles to the west. This rapid changing of shales to sandstone and then back again is very characteristic of the Chanute shales throughout the greater part of their extent. In the vicinity of Independence they appear principally as a sandstone, and the rich buff iron-stained soft sandstone of that place is the stratigraphic equivalent of the Chanute shales farther to the north. In places they grade over to rich bituminous shales carrying thin beds of coal, of little if any commercial value excepting in the vicinity of Thayer, where the coal reaches from 18 to 20 inches in thickness, and for more than twenty years has been mined to supply the local trade.

Iola Limestone.[42]

The name Iola limestone is here used to designate the large and prominent limestone lying first above the Chanute shales. It was first introduced by Haworth and Kirk in 1894, and has been used continuously and without question by every one writing on the geology of this part of the state from that time to the present.

Thickness.—The Iola limestone at Iola is 40 feet thick. To

42. Haworth, Prof. Erasmus, and Kirk, M. Z.: Kan. Univ. Quart., vol. II, p. 109. Lawrence.

the northeast it retains its thickness very well, measuring fully 30 feet thick in the bluffs at Kansas City. To the southwest is thickness decreases rapidly, being only about 8 feet thick in the stone-quarries near Chanute, where it has supplied so much broken rock for Chanute street-paving, and is no more than 1½ feet thick at Neodesha, where it can scarcely be recognized. South of Neodesha its existence is doubtful, but here and there are lentille-like masses of limestone, rarely reaching 2 feet in thickness, and apparently having no connection with each other, which stratigraphically correspond to the Iola limestone and quite likely should be looked upon as its southern extension.

Area.—The Iola limestone is one of the best-marked stratigraphic horizons in the state. Excepting its disappearance to the south, as just explained, it extends from the Chanute northeastward as a bold rock wall surmounting a well-defined escarpment almost continuous from Iola to Kansas City. In the southeast corner of Johnson county this escarpment crosses the state line into Missouri, but finally veers back westward up the Missouri river, as far north as Wolcott towards Leavenworth, up the Kansas river to beyond De Soto and up the Blue river and its tributaries in Jackson county, Missouri, and in the eastern parts of Johnson county, Kansas.

Characteristics.—The Iola limestone has some comparatively noted characteristics. It is particularly free from vertical fissures, which renders it possible to obtain large blocks for dimension stone in quarrying operations. An extensive quarry was once opened at Iola which produced large building stone valuable on this account. It is also noted for its excessively thick layers. At the Iola quarry almost the entire 40 feet was in one individual layer, thereby rendering quarrying processes very expensive. Northward, in both the vertical and horizontal beds, seams increase slightly, but to no great extent. At Kansas City it is the heavy limestone wall forming the picturesque landscape along the driveway of North Terrace Park. Here weathering processes have developed innumerable seams, so that it crumbles into small fragments under the influence of rain and frost. Yet it is exceedingly persistent and weathers away with difficulty, and is thereby largely accountable for the precipitous bluffs and creeks along the Missouri river.

The Iola limestone also is noted for its high crystalline character. It has a great many iron-stained cavities in it, many of

which are completely filled with calcite. A microscopic examination also shows that the body of the rock at Iola and elsewhere is practically crystallized, so that the name "Iola marble," formerly used, was not much of a misnomer. The Iola limestone is used very extensively at Iola for the manufacture of Portland cement. At the present time two different plants are located upon it at Iola, and two are building at Humboldt. At each mill it is mixed with the proper proportion of the overlying shale. Great quantities of chert lie in the soil just above this limestone in the eastern part of Miami county, perhaps disintregrated from its upper surface.

Fauna.—See Doctor Beede's chart, plate XLII.

Lane Shales.[43]

The term Lane shales was applied by Haworth in 1895 to the bed of shales first above the Iola limestone, and is here used with the same significance. In those early days, before positive correlations were possible, there was a little doubt as to its exact limitations. At present such doubt is all removed and, therefore, its exact position may be given as a shale-bed lying between the Iola limestone below and the Allen limestone above.

Adams,[44] entirely ignoring the use of this name, although it had been in good standing for ten years, has used in its place the name Concreto, probably in allusion to the manufacture of Portland cement at Iola. Why such disregard for well-established usage he does not mention.

Thickness.—The Lane shales vary in thickness from 30 or 40 feet up to a maximum of about 150 feet.

Area.—The Lane shales occupy a zone extending all the way from the south side of the state, in Montgomery county, northeastward, and approach the east state line in the vicinity of Stillwell, on the Missouri Pacific. Their outcropping line veers back a little to the west, so they appear on top of the hills at Kansas City, pass up the Kansas river almost to Eudora, and up the Missouri river to beyond Wolcott.

Characteristics.—The Lane shales in general character are very like the Chanute and Cherryvale shales, excepting that they do not carry much coal. Usually they are comparatively free from sand and consequently are valuable for brickmaking

43. Haworth, E.: Kan. Univ. Quart., vol. III, p. 277. Lawrence, 1895.

44. Adams, Dr. George I.: U. S. G. S., Bull. 238, p. 20. Washington, 1904.

and for the manufacture of Portland cement. At Neodesha they are used extensively for this purpose in combination with the overlying limestone.

Allen Limestone.[45]

The name Allen limestone is here used to designate the limestone first above the Lane shales. There has been a large amount of discussion regarding the names of the two limestones first above the Lane shales. In its early work this Survey was led into error a number of times on account of a lack of proper correlation. After Adams[46] joined the United States Geological Survey he likewise was incorrect in treating this subject. All along it has been known that there were two principal limestone formations moderately close together and sufficiently persistent to form a prominent line across the state. In 1894 these two were not differentiated, and in the section of the Neosho river were called by Haworth and Kirk the Burlington limestone. In the same publication, in a section from Coffeyville to Lawrence, Haworth recognized a limestone at Carlyle, which he named Carlyle, and these two limestone masses at Garnett and Ottawa, which he named the Garnett limestone. In volume III of this series of reports the term Garnett was used, Bennett having previously determined by field-work that the exposure at Carlyle was the lower of these two. In that way the name Carlyle was dropped. Adams[47] decided that the lower member, or possibly both of these, was the limestone mentioned by Swallow as the Stanton limestone. Later, in United States Geological Survey Bulletin 238 he abandoned the term Stanton and introduced the terms Allen and Piqua for these two limestone beds.

Our investigations have shown conclusively that the limestone named the Stanton by Swallow in his report for 1866 is the upper one of these two much discussed limestone formations. Inasmuch as we are now ready to give detailed descriptions and detailed names we adopt the name Allen for the lower one of the two, because it seems to be the first name suggested for this specific formation, and we retain the name Stanton for the upper one because Swallow suggested it as early as 1866. Our former name, Garnett, may be used, should any one

45. Adams, Dr. George I.: U. S. G. S., Bull. 238, p. 20. Washington, 1904.

46. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 41. Washington, 1903.

47. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 41. Washington, 1903.

wish to, for the combination of the two, as originally understood, but Adams's name, Piqua, for the upper one of the two must give way to Swallow's Stanton, unless priority be entirely ignored.

Thickness.—The Allen limestone varies in thickness probably more than any other limestone in the state, excepting the Drum. It ranges from 6 to nearly 75 feet. At Neodesha, on Little Bear Mound, at the Indian Portland Cement Company's plant, a number of dry holes have been put through it, some for the purpose of testing its thickness and some in the search for oil and gas. In no case did the drillers report less than 60 feet and some of them reported 100. It is probable, however, that this latter is somewhat of an exaggeration, and that 75 or 80 feet would include all of it. To the south, around Sycamore and Table Mound, it has a thickness equally great where not worn away by erosion. Northward from Neodesha this thickness is quite variable. In the vicinity of Greeley and Lane it is close to 40 feet thick, but at intervening places it is much less. At Carlyle it is 20 to 25 feet thick, while in the hills between Chanute and Vilas it is probably not more than 7 to 8 feet thick. On many of the hilltops where erosion is wearing it away it is but a few feet in thickness, and we are left to conjecture what its original thickness was.

Area.—The area occupied by the Allen limestone is practically coextensive with the Stanton, and the two will be described together under that head.

Characteristics.—The Allen limestone differs quite materially from ordinary limestones in its physical properties, on account of which it so readily breaks into small fragments by blasting. At the Indian Portland cement plant at Neodesha this property is carried to so great an extent that quarrying operations are conducted by first shooting the rock by dynamite and immediately gathering it with a steam-shovel, thereby quarrying it at an expense less than one-half of that of any other place in the state. Here it is mixed with the shaly material not so much along the bedding-plains as apparently a sort of brecciated mixture with the shaly material scattered irregularly through the limestone. This property in general is noticeable in many other places, and yet, broadly speaking, it is truly as stratified as limestones usually are. Also, it is highly crystalline, with many fragments of calcite an inch or more across. The so-called marble-quarries at Lane,

operated extensively a few years ago, obtained their material from the Allen limestone. Here the crystallization was carried to a high degree, sufficient to make almost the entire mass of the rock crystalline, but not so as to destroy its fossils.

Fauna.—The fauna of the Allen limestone is particularly interesting on account of its carrying so many fossil sponges where it is exposed to the surface from Chanute southwestward. These sponges are unusually numerous and well preserved, making quite a characteristic feature.

Vilas Shales.[48]

The name Vilas shales is here used to designate the shale lying just above the Allen limestone and below the Stanton. When the name was first suggested by Adams its exact application was not clearly defined because the position of the shale-bed was not then fully determined as regards limestones above and below. Adams thought that the Iola limestone extended southwestward, capping the hills at Neodesha, and that, therefore, the Vilas shales lay under the Iola. In this particular area he mistook the Allen for the Iola. Later he saw his mistake, and corrected it in United States Geological Survey Bulletin 238.

The shale-bed about Vilas to which he attached the name is now known to lie on top of the Allen limestone, its outcropping forming a narrow zone extending practically across the state, except where cut off by the tying of the limestone above and below it.

Thickness.—The Vilas shales vary greatly in thickness. At one point south of Vilas they are about 125 feet, and the outcropping line of the overlying limestone is carried back westward fully five miles from the outcropping line of the underlying limestone. To the southwest it thins rapidly and on the south bluffs of Fall river at Neodesha has a thickness of a little more than 5 feet. Still farther south it so nearly disappears that the two enclosing limestones practically become one and it can scarcely be distinguished at the south line of the state. To the northeast of Vilas the thickness decreases to about 10 feet, which diminishes to 5 feet at the Kansas river. Throughout the greater part of the distance northeastward from Garnett the Vilas shales are so thin that the enclosing limestones form one escarpment and may be considered as one.

48. Adams, Dr. George I.: Univ. Geol. Surv. of Kan., vol. III, p. 51. Lawrence, 1898.

Stanton Limestone.[49]

The name Stanton limestone is here used to designate the limestone first above the Vilas shales. Swallow[50] gives its locations as follows: "This limestone is well exposed in the eastern bluff of the Marais des Cygnes; in the highest points north of 'the Devil's Backbone' above Stanton." There can be no doubt, therefore, regarding his exact use of the term at this place. However, he may have been led into error in correlating it with other limestones in other parts of the state. This is the same limestone formation named Piqua by Adams,[51] as has been abundantly proved by the most careful field-work.

Thickness.—The Stanton limestone varies from 20 to 40 feet in thickness. It is a prominent limestone formation, with comparatively slight variations from point to point.

Area.—The Stanton limestone, in connection with the Allen lying first beneath, forms one of the most characteristic outcroppings in the eastern part of the state. Beginning on the southern border of the state in the vicinity of Caney they cap the high hills and escarpments, extending from Caney by way of Neodesha, Altoona and Benedict to the Kansas river and beyond into Missouri. On our surface map, plate VII*a*, VII*b*, VII*c*, the two limestones are mapped as one on account of their being so close together. Only at one place, Vilas, do they separate sufficiently so that this mapping would be incorrect. Here, as already explained, the Vilas shales reach a great thickness and the two limestones are pushed farther apart.

West from the outcropping line in some places extensive dip slopes cover a zone five to twenty miles wide. This also reaches its maximum width opposite Vilas. Here the Stanton limestone covers the surface almost all the way from Vilas southwest to New Albany, making a broad plain with a gentle westward dip throughout the entire area. The zone lying between the outcropping of the Oread limestone and the Stanton limestone in most places should be looked upon as a dip slope of the latter.

The Stanton limestone also is exposed at the surface at Olathe, and the dip slope, with a thin covering of soil and shale, extends all the way west to Lawrence, a distance of nearly thirty miles. In brief, the upper surface of the Stanton lime-

49. Swallow, Dr. G. C.: Geology of Kansas, p. 75. Lawrence, 1866.

50. Swallow, Dr. G. C.: Geology of Kansas, p. 75. Lawrence, 1866.

51. Adams, Dr. George I.: U. S. G. S., Bull. 238, p. 20. Washington.

stone occupies almost the entire surface from its outcropping line on the east to the Oread on the west, with the Lawrence shales here and there forming a thin covering of variable thickness.

Characteristics.—The Stanton limestone in most respects is quite similar to others in this part of the state. It is well bedded, yielding thin individual layers, in most places separated by thin shale partings. At the stone-quarry at Benedict, however, some of the limestone layers are from 6 to 8 feet thick. Elsewhere one of these shale partings assumes considerable importance and becomes a rich, bituminous shale from 4 to 8 feet thick. In the vicinity of Princeton, for example, along the Santa Fe track at a crossing of one of the branches of the Pottawatomie, some one apparently has mistaken this jet-black shale for coal and has mined quite a volume of it, only to leave it lying on the ground unused. At Ottawa the same shale-bed has a thickness of 7 feet and preserves its bituminous character. Good exposures of this bituminous shale can be seen at Eudora, in Douglas county, and at Linwood, in Leavenworth county.

Fauna.—See Doctor Beede's chart, plate XLII.

Le Roy Shales.[52]

The name Le Roy shales is used here to designate the shale first above the Stanton limestone and first below the Kickapoo limestone. In 1894 Haworth and Kirk recognized them in their section along the Neosho river. Later they were supposed to be correlated with the Lawrence shales so well exposed farther north. In those days of imperfect correlation it was difficult to determine just what were their equivalents north and south. We are now able to say that they have a sufficient existence to warrant a separate name.

Thickness.—The Le Roy shales vary in thickness from 60 to 100 feet. They are about 100 feet thick in the vicinity of Le Roy and to the south. From here northward they gradually decrease to the west of Ottawa and then increase to 100 feet in the vicinity of Lawrence, and gradually grow thinner to the northward to about 60 feet.

Area.—The Le Roy shales occupy a zone along the dip slope of the Stanton limestone and extend from the south side of

52. Haworth, Prof. Erasmus, and Kirk, M. Z.: Kan. Univ. Quart., vol. II, p. 110. 1894.

the state in Chautauqua county northward to the Missouri river in the vicinity of Leavenworth.

Characteristics.—The Le Roy shales have yielded a limited amount of coal; and this mainly in the vicinity of Lawrence.

Fauna.—See Doctor Beede's chart, plate XLII; and for list of flora see chapter by Doctor Sellards.

Kickapoo Limestone.[53]

The name Kickapoo limestone is here used to designate a thin limestone found in places here and there entirely across the state, from the state line in Chautauqua county northward to Doniphan county beyond Atchison. It is not very important, except at its outcrop in Doniphan county, and had been overlooked in a measure in our earlier field-work. On account of its persistence, however, throughout a distance of 200 miles, its importance is readily recognized. It is the lenticular limestone of Willow creek, described by Schrader,[54] in his description of the Independence quadrangle area.

Thickness.—The Kickapoo limestone varies from 5 to 15 feet in thickness. Its greatest thickness is to the north, in Doniphan county, where it is well formed and very persistent. At Lawrence it is only 3 or 4 feet thick, but at the eastern foot of Blue Mound, six miles southeast of Lawrence, it is fully 10 feet. Southward in general it decreases in thickness and in some places it scarcely recognizable. At the ford north of Coyville, on the Verdigris river, it is about 8 feet thick. From here southward to the south side of the state it is persistent.

Characteristics.—In Doniphan county it forms great blocks on the face of the hills along the valley of the Missouri river.

Fauna.—See Doctor Beede's chart, plate XLII.

Lawrence Shales.[55]

The Lawrence shales are so named by Haworth on account of the good exposure at the city of Lawrence and to the south and north of that place.

Thickness.—The Lawrence shales vary in thickness from 200 to 300 feet, which latter is their maximum thickness, as found in the extreme southern part of the state, in Chautauqua county.

53. Bennett, Rev. John: Kan. Univ. Geol. Surv., vol. 1, p. 61. Lawrence, 1896.

54. Schrader, Dr. F. C.: U. S. G. S., Bull. 296, p. 12. 1906.

55. Haworth, Prof. Erasmus: Kan. Univ. Geol. Surv., vol. 1, p. 136. Lawrence, 1896.

Area.—They extend all the way in a broad belt from the southern part of Chautauqua county until they reach the Missouri river above Leavenworth, when they decrease somewhat throughout Atchison county and further north.

Characteristics.—In their northern outcrop they are mainly clay shales, but to the south, and especially from Woodson county to the extreme southern part of the state, they become quite arenaceous, although not so much so as is usually supposed. The hills which they compose in this southern extension are covered by sandstone to their base, and a casual observer is led to think that the entire hill is composed of sandstone, while in reality the upper portion is sand and the lower three-fourths, at least, are mainly clay shales. Adams[56] suggested the name Chautauqua, after Chautauqua county, for these sandstones, as a local designation, on account of their abundance in the areas which the Lawrence shales cover to the south. Coal is found in all of these shales at different horizons from the extreme north to Chautauqua county. These coals are of some commercial importance in Franklin county, and formerly were mined for home consumption to a considerable extent in Douglas county. The beds afford a very good quality of coal in Atchison county, which is still used in parts of that county for domestic purposes. Two or three thin limestones were found within these shales in lenticular masses at various horizons, especially in the north.

Oread Limestone.[57]

The name Oread limestone, given by Haworth, is used for the limestones just above the Lawrence shales. The name was given to these limestones because they cap the hill known as Mount Oread, on which the Kansas State University stands. It has been used continuously by this Survey since its first introduction. There are three fairly distinct individual members of the limestone separated by thin shale beds.

Thickness.—The upper member of the Oread is variable in thickness, being from 10 to 25 feet where exposed; the middle member has a uniform thickness of less than 2 feet; the lower member is from 8 to 12 feet thick. The upper separating is shale from 6 to 15 feet thick and the other from 20 to 60 feet thick. The whole formation throughout the middle portion of

56. Univ. Geol. Surv. of Kan., vol. III, pp. 58, 59. 1898.

57. Haworth, Erasmus: Kan. Univ. Quart., vol. II, pp. 123, 124. Lawrence, January, 1894.

the state measures from 40 to 50 feet. In Greenwood county the lower limestone is separated farther from its companions, and by the time Longton is reached in a southward journey it is found to be 60 or more feet away and thins out so that it was nowhere seen south of that town. Likewise it was not found north of Atchison.

Area.—From the relations of the different limestone masses constituting the Oread limestone, their outcropping lines form but one escarpment, which is very prominent from Doniphan county to Chautauqua county. The upper Oread limestone passes out of the state southward near Elgin and under the Missouri river on the north side of Doniphan county.

Characteristics.—The upper of these Oread limestones is a gray rock throughout its extent, but somewhat darker at its southern end than elsewhere. Chert nodules are very abundant in it. The lower limestone weathers buff to brown, but has an exceptionally light layer in the hills south of Lawrence. It carries a few chert concretions but not nearly so many as the upper. The thin middle limestone, although only 2 feet thick or less, has a persistency of lateral extent far beyond any reasonable expectation. It is continuous from the extreme north to the extreme south of the entire Oread outcroppings within the state. Very large slabs of this thin limestone cap the hills north of Sedan. It also forms the platform on the University campus, in front of Fraser Hall. The Oread limestones are quite hummocky in Elk and Chautauqua counties, forming dome-like hills with little irregularity, and are flexed near Yates Center, Woodson county, at the head of Owl creek, and also at Pomona, in Franklin county. The lower intervening shales are mainly olive-colored clays. The upper have a bituminous bed just above the middle limestone. And here it might be said that this bituminous bed is as persistent as the thin limestone below it from the extreme north to the extreme south.

Kanwaka Shales.[58]

The name Kanwaka shales was given by Adams to the shales occupying the interval between the Oread and Lecompton limestones, so named after a municipal township in Douglas county, where they occupy a large portion of the surface.

Thickness.—The Kanwaka shales vary in thickness from 50 to 100 feet.

58. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 45. Washington, 1903.

Area.—Kanwaka shales form a narrow surface zone throughout their extent across the state from north to south. Northward the shale-beds grow thinner and their outcropping correspondingly narrower.

Characteristics.—The Kanwaka shales are mainly in the form of clays, with here and there thin seams of coal, which are of no commercial value. A calcareous flagging stone is obtained from these shales at Waverly and elsewhere, existing as lenticular masses of argillaceous limestone, which lie not far above the Oread limestone, seen from Coffey county northward to perhaps beyond the Kansas river. The remarkable limestone lentille just east of McLouth, on Tonganoxie creek, is its equivalent, although differing from it in characteristics.

Lecompton Limestones.[59]

This name was given to these limestones by Bennett. They are named from the town which was at one time the territorial capital of what is now the state of Kansas. They lie immediately above the Kanwaka shales.

Thickness.—The Lecompton limestones, taken together with their intervening shales, fill a vertical space of from 15 to 30 feet at Lecompton and north, but in the southern part of the state they separate much more.

Area.—The Lecompton limestones cover a small space from north to south on account of the arenaceous beds above them which crowd upon their outcrop from the Kansas river to the extreme south, and also where it is seen to the north of the Kansas river.

Characteristics.—The Lecompton limestone is noted locally on account of the excellent building stone it produces. North of the Kansas river it yields large, beautiful slabs, used extensively in Lawrence for curbing-stone and for trimmings in large buildings.

Also great quantities of *Fusulina* begin to appear in the Lecompton limestones.

Tecumseh Shales.[60]

The Tecumseh shales are so named by Beede. They fill the interval between the Lecompton and the Deer Creek limestone.

Thickness.—The Tecumseh shales vary from 40 to 70 feet in thickness, and are of an arenaceous character; which, coupled

59. Bennett, Rev. John: Univ. Geol. Surv. of Kan., vol. I, p. 116. 1896.

60. Beede, Dr. J. W.: Kan. Acad. Sci., vol. XV, pp. 27-34. 1896.

with the limestones above and below, forms, from the valley of the Kansas river southward, the scarp called for convenience the Elk Falls escarpment.

Area.—The Tecumseh shales cover but a narrow strip of the surface of the country from north to south, but form, as has been said, the face of the escarpment, with the Deer Creek limestone capping the same.

Deer Creek Limestone.[61]

Bennett named these limestones from their location on Deer creek east of Topeka. Here again we have a three-membered limestone series separated by two shale-beds, the upper one 4 feet thick and the lower one about 10 feet thick.

Thickness.—The Deer Creek limestones fill a vertical space of from 20 to 30 feet. The lower one is 6 feet thick, the middle one 2 feet, and the upper one about 5 feet along the Kansas river.

Area.—The Deer Creek limestones form an irregular narrow zone or small escarpment, extending from the southern part of the state northward until hidden by the glacial drifts in Jefferson county.

Characteristics.—The Deer Creek limestones become quite blue in color towards the south, and are much fissured and broken as they appear on the hilltops in the southern part of the state. These characteristics are quite uniform wherever observable.

Calhoun Shales.[62]

The Calhoun shales were named by Beede, the name being applied to a shale above the Deer Creek and below the Topeka limestone.

Thickness.—The Calhoun shales measure perhaps 50 feet thick at Topeka, but thin out both to the north and to the south.

Topeka Limestones.[63]

The Topeka limestones were named by Bennett. They are a quadruple series and have been extensively quarried for building purposes at Topeka, from which place they derive their name. They lie immediately above the Calhoun shales.

61. Bennett, Rev. John: Univ. Geol. Surv. of Kan., vol. I, p. 117. 1896.

62. Beede, Dr. J. W.: Trans. Kan. Acad. Sci., vol. xv, pp. 29. 1896.

63. Bennett, Rev. John: Univ. Geol. Surv. of Kan., vol. I, p. 117. 1896.

Thickness.—The Topeka limestones, with their included shale partings, measure from 20 to 25 feet.

Area.—The Topeka limestones, lying as they do on the top of an escarpment near Elk Falls, seldom come to its face, and constitute the floor of a dip slope extending westward toward the Howard scarp. The width of this dip slope is variable according as the Howard escarpment reaches to or recedes from the one near Elk Falls.

Characteristics.—The lower members of the Topeka limestones in the vicinity of Topeka are quite blue in color. East of Moline they weather buff. The upper layers are charged with much calcite. In this part of the state, also, the shale partings largely disappear so the limestones come together in one body. Many fine fossils may be taken from the small seams of clay shale partings.

Severy Shales.[64]

The name Severy shales was applied by Adams to the outcrop bounded by the Topeka limestone below and the Howard limestone above. The town of Severy, from which the name was taken, is built on these shales.

Thickness.—The Severy shales vary from 40 to 60 feet and are mainly clay shales carrying some bituminous matter.

Area.—The Severy shales, forming mainly the face of the Howard escarpment, have nowhere a very wide area, except a small widening north of Osage City.

Characteristics.—Included within the Severy shales is what is known as the Osage county coal. This coal varies in thickness from 8 to 20 inches and in Osage county constitutes the workable coal. The shales are coal-bearing everywhere in the entire extent from Nebraska to the Oklahoma line.

Howard Limestone.[65]

The name Howard limestone was given by Adams to the limestone lying just above the Severy shales which cap an escarpment somewhat persistent from Valley Falls, in Jefferson county, to the south end of the state. It lies a few feet above the coal at Scranton, Carbondale, Osage City and Topeka.

Thickness.—The Howard limestone is from 2 to 7 feet thick, and in places forms two beds separated by 1 or 2 feet of shale.

Area.—The Howard limestone quite frequently forms dip

64. Adams, Dr. George I.: Univ. Geol. Surv. of Kan., vol. III, p. 67, 1898.

65. Adams, Dr. George I.: Univ. Geol. Surv. of Kan., vol. III, p. 67. 1898.

slopes extending westward to the Burlingame escarpment, but in places the superincumbent shales form a heavy blanket over this dip slope. In the northern part of the state it is covered by glacial drift.

Scranton Shales.

This shale-bed lies between the Howard and the Burlingame limestones. Haworth,[66] Hall[67] and Adams[68] called them the Burlingame shales and other names, but the name Burlingame was given to limestone above the shales at the same time and therefore the name Scranton is now applied to these shales.

Thickness.—The Scranton shales, from 160 to 180 or more feet thick, stand in the face of one of the prominent escarpments of eastern Kansas.

Area.—They cover a somewhat extended area from the southern part of the state to Arrington, in Atchison county, where they pass under the glacial drift.

Characteristics.—The Scranton shales have a vein of coal of little importance about one-half of the way up in them which is seen in the Burlingame escarpment in many places, and immediately above this coal is a calcareous bond, becoming a firm limestone in places, and at points west of Topeka thickens to 2½ feet. It is not persistent, however, and therefore would not form a division line.

Burlingame Limestone.[69]

The name Burlingame was given to this limestone by Hall. It caps what is known as the Burlingame escarpment.

Thickness.—The Burlingame limestone varies in thickness from 6 to 12 feet. It is split by thin shales in the southern outcrop. It forms, in Brown county, but one solid layer.

Area.—The Burlingame limestone occupies a somewhat narrow strip of country from south of Cedar Vale, in Chautauqua county, ranging from one to five miles or so until it passes into Nebraska north of Brown county. This limestone goes under a mantle of glacial drift at Muscotah, comes out again northeast of Everest, goes under again at Robinson, and appears again on Roys creek before the Nebraska line is reached.

Fauna.—See Doctor Beede's chart, plate XLII.

66. Haworth, Prof. E.: Univ. Geol. Surv. of Kan., vol. 1, p. 162. 1896.

67. Hall, J. G.: Univ. Geol. Surv. of Kan., vol. 1, p. 104. 1896.

68. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 51. Washington. 1903.

69. Hall, J. G.: Univ. Geol. Surv. of Kan., vol. 1, p. 105. 1896.

Willard Shales.[70]

These shales were named by Beede from a little village by that name on the south side of the Kansas river about fifteen miles above Topeka, and is used to designate the shales between the Burlingame and Emporia limestones. Adams[71] called them the Olpe shales subsequently, as appears, to the time they were named by Beede.

Thickness.—The Willard shales are, perhaps, in the vicinity of Olpe, not over 60 feet. Smith[72] makes this interval a little less in Lyon county—that is, reckoning up to his "Emporia Blue"; but if the interval be carried up to what he calls the Emporia system the interval would be about 190 feet.

Area.—The Willard shales area is small to the south and possibly not any larger to the north.

Characteristics.—The Willard shales are mainly clays throughout their extent.

Emporia Limestone.[73]

This name is applied by Kirk and designates the limestone above the Willard shales. These limestones are described by Smith,[74] and Prosser[75] draws his description from Smith, as follows: The Emporia limestone "is composed of three feet of hard blue limestone at the base, the upper 6-inch layer making a good flagstone which is extensively used in Emporia. Then there is 4 feet of shale capped by another hard blue limestone 2 feet in thickness." The blue limestone may be the equivalent of that seen by Bennett[76] in his Kansas river section west of Topeka, near Willard.

Thickness.—The Emporia limestone is about 9 feet in thickness, and is found in two layers separated by about 4 feet of shale.

Area.—The Emporia limestones form but a narrow area extending throughout their entire outcrop.

Fauna.—See Doctor Beede's chart, plate XLII.

70. Beede, Dr. J. W.: Trans. Kan. Acad. Sci., vol. xv, p. 31. Topeka, 1898.

71. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 52.

72. Smith, Alva J.: Bull. Lyon County Geology, p. 2. 1902.

73. Kirk, M. Z.: Univ. Geol. Surv. of Kan., vol. I, p. 80. 1896.

74. Smith, Alva J.: Bull. Lyon County Geology, p. 3. 1902.

75. Prosser, Dr. Chas. S.: Jour. of Geol., vol. x, No. 7, p. 706. 1902.

76. Bennett, Rev. John: Univ. Geol. Surv. of Kan., vol. I, p. 119. 1896.

Admire Formation.[77]

The Admire formation was named by Adams. Prosser[78] quotes from Smith[79] and says of this formation that its thickness is about 300 feet.

Area.—The area of the Admire formation is not given by any writer except that described by Smith for Lyon county, but undoubtedly lies, like all others, from the extreme north to the extreme south part of the state, and forming quite a zone.

Characteristics.—The Admire formation is composed of not less than thirteen thin limestones with occasional sandstones and two or more seams of coal.

Americus Limestone.[80]

Haworth and Kirk named this the Americus limestone on account of its exposure and the quarries in it at that place. It lies just above the Admire formation.

Thickness.—Prosser[81] says that the Americus limestone is about 8 feet thick.

Characteristics.—The Americus limestone is considered a good building stone and in Greenwood county, where it is broken from the outcrop, lies along the face of the escarpment, which it caps, like sheep resting on the hillside.

Fauna.—See Doctor Beede's chart, plate XLII.

Elmdale Formation.[82]

This is so named by Prosser and Beede. It is exposed east of the town from which it takes its name, and occupies the space between the Americus limestone below and the Neva limestone above.

Thickness.—The Elmdale formation is about 130 feet thick.

Characteristics.—Prosser[83] says that the Elmdale shales are "thin beds of grayish alternating limestone including two or three thicker ones. About 30 feet above the base of the forma-

77. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 53. 1903.

78. Prosser, Dr. Chas. S.: Jour. Geol., vol. x, p. 707.

79. Smith, Alva J.: Geol. of Lyon County, p. 3. 1902.

80. Kirk, M. Z.: Univ. Geol. Surv. of Kan., vol. I, p. 80. 1896.

81. Prosser, Chas. S.: Jour. of Geol., vol. x, No. 7, p. 708. 1902.

82. Prosser, Chas. S., and Beede, Dr. J. W.: Jour. of Geol., vol. x, p. 718, diagram. 1902.

83. Prosser, Chas. S.: Jour. of Geol., vol. x, No. 7, p. 708. 1902.

tion is a friable limestone with a thickness in some localities of 4 feet, which is composed to a large extent of the tests of *Fusulina secalica* Say. About 30 feet above its base it abounds in *Fusilina.* About 30 feet higher is another conspicuous yellow limestone."

Fauna.—See Doctor Beede's chart, plate XLII.

Neva Limestone.[84]

Prosser and Beede gave this name to this limestone, Neva, from whence it is taken, being a station on the Atchison, Topeka and Santa Fe railroad. It lies immediately above the Elmdale formation.

Thickness.—The Neva limestone is 10 feet or more thick, in two members.

Characteristics.—Prosser[85] says the Neva limestone "breaks off in large blocks with sharp angles and a rough, jagged surface, weathering to a color not dissimilar to that of bleached bones."

Fauna.—See Doctor Beede's chart, plate XLII.

Eskridge Shales.[86]

From large exposures of these shales near Eskridge the name was given by Prosser and Beede. It fills the interval between the Neva limestone and the Cottonwood limestone.

Thickness.—The Eskridge shales are from 30 to 40 feet thick, according to Prosser, in the volume so often quoted.

Characteristics.—The Eskridge shales, with the exception of a few thin limestones in them, are massive greenish, chocolate, and yellowish clays.

Fauna.—See Doctor Beede's chart, plate XLII.

Cottonwood Limestone.[87]

The name Cottonwood limestone or Cottonwood Falls limestone is a commercial term used by the trade for an indefinite period before it was applied to a definite geologic horizon. Extensive stone-quarries were opened up in the vicinity of Cottonwood Falls and stone shipped to many places for erecting costly buildings. In the summer of 1893, Haworth and Kirk

84. Prosser, Chas. S.: Jour. of Geol., vol. x, No. 7, p. 718, diagram. 1902.

85. Prosser, Chas. S.: Jour. of Geol., vol. x, No. 7, p. 709. 1902.

86. Prosser, Chas. S., and Beede, J. W.: Jour. of Geol., vol. x, No. 7, p. 718, diagram. 1902.

87. Haworth, E., and Kirk, M. Z.: Kan. Univ. Quart., vol. II, p. 112. 1894.

made a geologic section up the Neosho and Cottonwood rivers. Their first report was published in January, 1894, and the name Cottonwood Falls limestone formally given to their number 13 of this section. Later, in 1894, Prosser introduced the term "Cottonwood formation," including the Cottonwood Falls limestone and the overlying shale-bed. For the limestone he used the word "Cottonwood" rather than Cottonwood Falls, and in a number of publications since that date has adhered to the name Cottonwood. To simplify matters, therefore, this Survey, in volume III, used the word Cottonwood, which was considered unobjectionable, as the change was so little, and particularly as the commercial name was used indiscriminately, either Cottonwood or Cottonwood Falls. In 1902 Prosser[88] suggested the name Alma limestone instead of Cottonwood limestone, on account of the name Cottonwood being previously used by N. F. Drake in connection with Texas geology. In a letter, however, to Mr. Bennett, in 1907, Professor Prosser states that "Cottonwood or Cottonwood Falls would be the correct nomenclature." We are not informed of the details for Professor Prosser changing his mind as shown by this letter. The commercial use of the name Cottonwood is so extensive this Survey would be entirely powerless to make a change from Cottonwood to Alma were we to attempt it. Therefore, we will continue the use of the name Cottonwood.

Thickness.—The Cottonwood limestone has a thickness of about 6 feet, or more.

Area.—The Cottonwood limestone has an outcrop from Nebraska to the Indian Territory line. Nowhere, however, can it be said that it occupies the surface of the country to any great extent.

Characteristics.—For these characteristics in part we will quote Prosser:[89] "This is a massive light-gray, buff-colored, foraminiferal limestone, frequently composed of two layers. . . . It contains very few fossils, with the exception of *Fusulina secalica* Say, which is extremely abundant in its upper part and is called 'wild rice' by the quarrymen. It is the most important dimension stone in Kansas, and at various localities are extensive quarries. Its constant lithologic character, with its line of outcrop frequently marked by a row of massive light-gray rectangular blocks filled with *Fusilina*,

88. Prosser, Chas. S.: Jour. of Geol., vol. x, No. 7, pp. 711, 712. 1902.

89. Prosser, Chas. S.: Jour. of Geol., vol. x, No. 7, p. 711. 1902.

make it one of the most important stratigraphic horizons in the Upper Paleozoic rocks for at least two-thirds of the distance across Kansas and into Nebraska."

Fauna.—See Doctor Beede's chart, plate XLII.

Garrison Formation.[90]

The Garrison formation, so named by Prosser, fills the interval between the Cottonwood and the Wreford limestone.

FLORENA SHALES.—This name, Florena shales, was given by Prosser and Beede,[91] from the exposure over the Cottonwood limestone in the quarries near Florena, in the Big Blue valley.

THE NEOSHO MEMBER.—This was so called by Prosser.[92] He says: "This member was originally termed the Neosho formation, from the excellent outcrop in the Neosho valley near Council Grove. The Florena shales and the Neosho member are now united to form the Garrison formation, so named on account of the good exposures from Garrison south in the Big Blue valley."

Thickness.—The Garrison formation is put at from 140 to 150 feet in the volume so frequently quoted here, where Prosser also states that "the lower shales have a thickness of 13 feet near Strong."

Area.—The Garrison formation very frequently is seen only in an escarpment which is capped by the Wreford limestone; while again they occupy the platform under which the Cottonwood limestone lies. It extends from the Nebraska line to the southern part of the state.

Characteristics.—The Florina shales are literally impregnated with a limited species of fine fossils in their entire outcrop. Near the base of the Neosho member in the Big Blue valley a bed of gypsum is found. This upper member is formed of green, chocolate and yellow shales, alternating with grayish limestones.

Fauna.—See Doctor Beede's chart, plate XLII.

Wreford Limestone.[93]

The Wreford limestone was named by Hay from a little sta-

90. Prosser, Chas. S.: Jour. of Geol., vol. x, No. 7, p. 712. 1902.

91. Prosser, Chas. S., and Beede, J. W.: Jour. of Geol., vol. x, No. 7, p. 712, diagram. 1902.

92. Prosser, Chas. S.: Jour. of Geol., vol. III, p. 764. 1895.

93. Hay, Robert: Eighth Bien. Rep. State Bd. of Agr., pt. II.

tion south of Junction City on the Missouri, Kansas & Texas railroad, where it was quarried and burned for lime. It lies at the top of the Garrison formation and forms the basal part of the Permian rocks which lie above it and fill the space until the Cretaceous formations are reached.

Thickness.—Prosser[94] says: "Throughout the Flint Hills region it varies from 35 to 55 feet." To the north it becomes much thinner, as well as to the south near the Oklahoma line.

Area.—The Wreford, like all the other formations, has its peculiar area and differs little from the others except that, standing as it does at or near the crest of the Flint Hills from southern Marshall to Cowley counties, it is the underlying rock of an extended dip slope at times. It trends, like some of the other formations, from Nebraska to the Oklahoma line, and the escarpment is always in bold relief except where covered north of the Kansas river by the glacial drift.

Characteristics.—The Wreford limestone carries much more chert than any of the limestones before mentioned. It is then composed of three strata, a cherty limestone above and below separated by heavy limestones nearly free from chert. It sometimes carries a thin layer of shale between the cherty limestones, as at Reece,[95] and in its southern extension it is characterized by large blocks of imperfectly silicified limestone, which weather to a reddish-brown and are very porous. They are called "sand rock" by the inhabitants. This abundance of chert, which is slow of disintegration, and this outcrop, probably on the axis of an anticlinal, put it on or near the crest of an elevation which from the above facts is called the Flint Hills.

Matfield Shales.[96]

The Matfield shales were named by Prosser and Beede from a township in Chase county. They cover the rapid dip slope between two heavy flint formations, the Wreford and the Florence flint.

Thickness.—The Matfield shales range from 60 to 70 feet in thickness.

Area.—The area of the Matfield shales is not very exten-

94. Prosser, Chas. S.: Jour. of Geol., vol. x, p. 713. 1902.

95. Beede and Sellards: Am. Geol., xxxvi, Nos. 41-52, p. 97. 1905.

96. Prosser, Chas. S., and Beede, J. W.: Jour. of Geol., vol. x, p. 718, diagram. 1902.

sive, forming as they do the rapid slope between two cherty formations.

Characteristics.—The Matfield shales are variously colored, says Prosser, "with some shaly buff, occasionally cherty, limestone, and a light-gray limestone 2 feet or so in thickness, which occurs about 30 feet below its top."

Florence Flint.[97]

The Florence flint was so named by Prosser. It lies just above the Matfield shales.

Thickness.—The Florence flint ranges from 19 to 23 feet in thickness.

Area.—The Florence flint has its proper area and, like the Wreford flint, forms a dip slope to the west for some distance. Its outcrop closely parallels that of the Wreford limestone.

Characteristics.—The Florence flint is a very cherty limestone 19 to 23 feet in thickness. It is composed of thin limestones with interbedded chert, and in some places contains a thin, white, cellular sandstone in the middle. Fine exposures of this stone occur at Oketo, Grant, Valencia, and wherever east and west railroads cross the Flint Hills escarpment. Both the Florence Flint and the Wreford limestone are extensively used for ballast.

Fort Riley Limestone.[98]

The Fort Riley limestone was so named by Swallow from the place which bears that name. It lies immediately above the Florence flint.

Thickness.—The Fort Riley limestone has a thickness of 40 to 47 feet.

Area.—The area of the outcrop of this limestone is sometimes quite extensive, while again the plateau above it has lying upon it deposits of Doyle shale.

Characteristics.—The basal part of the Fort Riley limestone is either shaly, or marly, or a shale. At Oketo it is a soft, shaly limestone or very calcareous shale. At Marysville and Junction City it is represented by about 9 feet of fossiliferous calcareous shales, while at Florence they are thinner. Resting upon this layer are one or two layers of thick, buff, cellular

97. Prosser, Chas. S.: Jour. of Geol., vol. III, p. 773. Unaccredited quotations in the discussion of the Permian rocks are from Prosser, Jour. of Geol., vol. X, pp. 714-737.

98. Swallow, G. C.: Prelim. Rep., Geol. Surv. Kan., p. 14. Lawrence, 1866.

limestones 3½ to 5 or more feet in thickness, which form the very conspicuous escarpment of this formation. The remainder of the limestone layers are thin and all of them are soft, hardening upon exposure. In some places, as at Oketo, some of them are oolitic. Swallow[99] describes the ledge at Fort Riley in 1866 as "a buff porous magnesian rock in thick beds." It now covers what was at one time called the Florence limestone.

Doyle Shales.[100]

Prosser and Beede named these shales because exposed on Doyle creek, a tributary of the Cottonwood river, south of Florence. They fill the interval between the Fort Riley limestone and the Winfield formation.

Thickness.—The Doyle shales are 60 feet thick.

Area.—The Doyle shales occupy a wider area south of the Kansas river and north of it than do some of the preceding formations.

Characteristics.—The Doyle shales are variously colored and contain thin slabs of limestone. "About twenty feet above the base is a thin grayish limestone which often appears on the surface, and at the top are yellowish shales containing a few fossils. These shales and the rocks of the overlying formations weather easily and form gently undulating prairies in sharp contrast with the rough topography produced by the flint and massive limestones below."

Winfield Formation.[101]

This formation was named by Prosser from its prominent outcrop around Winfield, Cowley county. It lies between the Doyle shales and the Marion formation above.

Thickness.—The Winfield formation is about 25 feet in thickness in the central and southern part of the state. North of the Kansas river, especially toward the Nebraska line, it seems to become very much less conspicuous and thinner owing to the apparent thinning out of the limestones and the thickening of the shales.

Area.—The Winfield formation has quite an extensive area, at least southwest of the Flint Hills. From the Cottonwood

99. Swallow, G. C.: Prelim. Rep., Geol. Surv. Kan., p. 14. Lawrence, 1866.

100. Prosser, C. G., and Beede, J. W.: Jour. of Geol., vol. x, p. 718, diagram. 1902.

101. Prosser, Chas. S.: Univ. Geol. Surv. of Kan., vol. II, p. 64. 1897.

river to the north it becomes narrower until the Nebraska line is reached.

Characteristics.—The Winfield formation is "composed of a cherty limestone at the base with a massive concretionary one at the top, the two separated by yellowish shales. This chert and concretionary limestone form the highest prominent chert ledge in the Kansas Permian, and make a marked stratigraphic horizon that is of great assistance in determining the areal geology of eastern central Kansas."

Marion Limestone.[102]

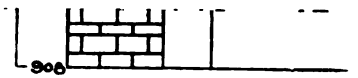
This name was given by Prosser and is applied by him to the rocks immediately above the Winfield formation and below the Wellington shales.

Thickness.—Adams[103] says that its thickness has been estimated at between 300 and 400 feet. Later estimates show it to be but about 150 feet.

Characteristics.—"Buff, thin-bedded limestones and shales form the principal part of this formation. The lower part is composed of rather soft, porous, thin-bedded and shaly layers to shales, containing near the base a considerable number of siliceous geodes and occasionally some chert. Some 50 or 60 feet above the base is a buff limestone containing large numbers of small lamellibranches, as *Pleurophorus subcuneatus* M. & H., *Bakewellia parva* M. & H., *Yoldia subscitula* M. &. H., and other species, while about 20 feet higher is another similar limestone containing large lamellibranches, as *Aviculopecten occidentalis* (Shum.), *Myalina permiana* (Swallow) and *Pseudomonotis hawni* M. & H. A limestone containing *Pleurophorus* occurs in some localities near the horizon which also contains large cherty concretions."

102. Prosser, Chas. S.: Jour. of Geol., vol. III, p. 786. 1895.

103. Adams, Dr. George I.: U. S. G. S., Bull. 211, p. 60. 1903.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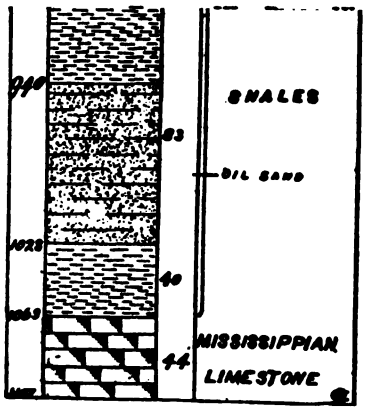
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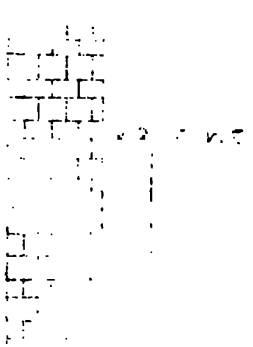

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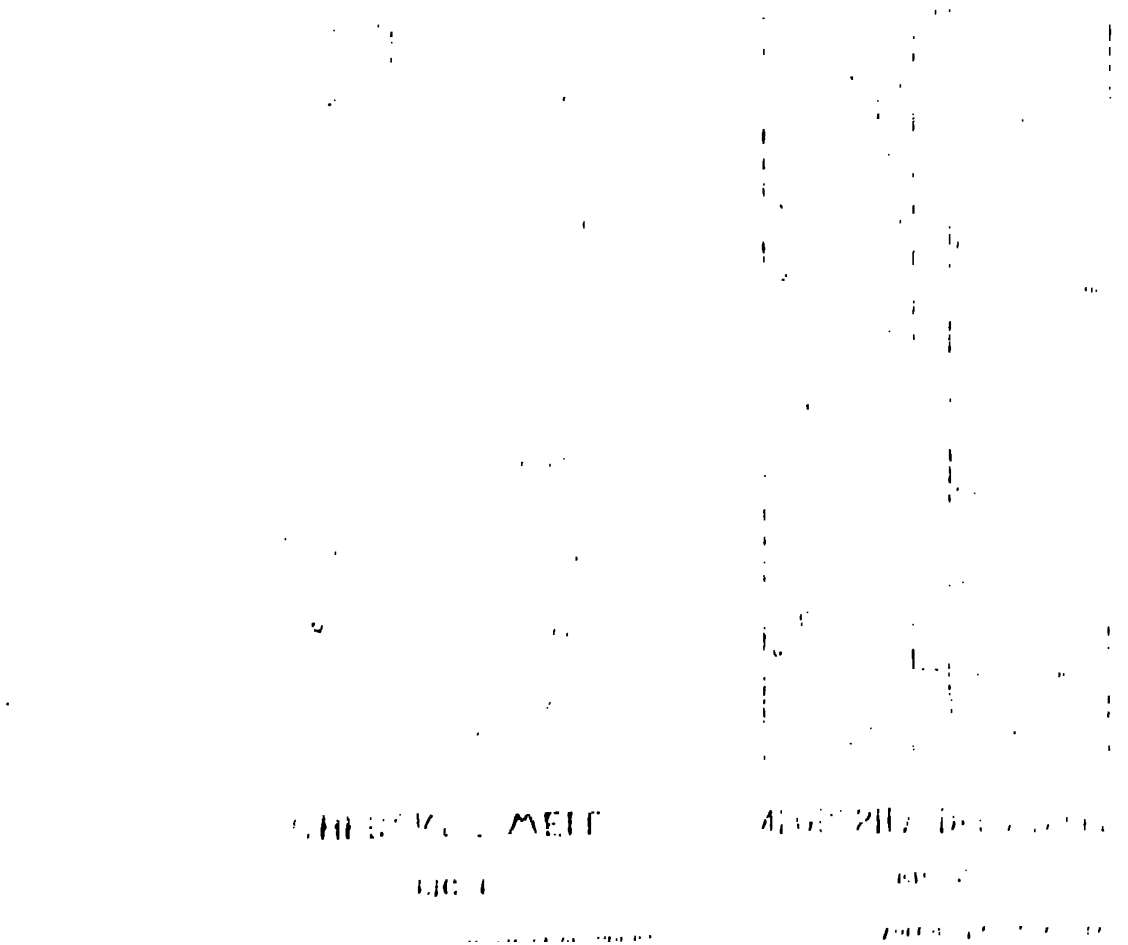
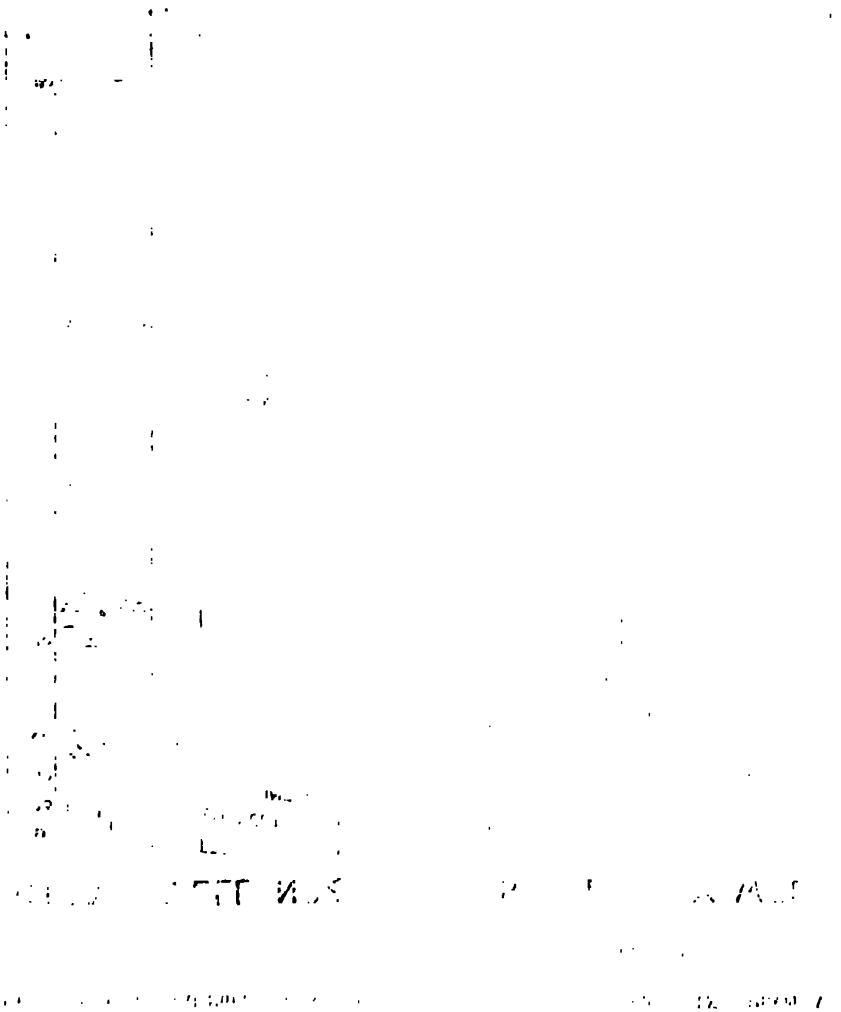


NEOSHA DUPLEX WELL

CHEROKEE WELL



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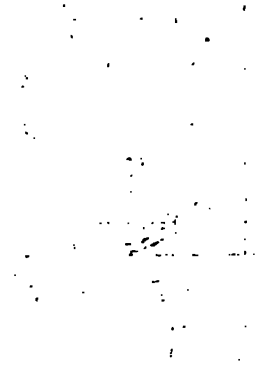
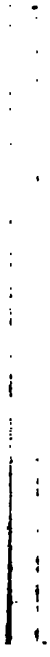
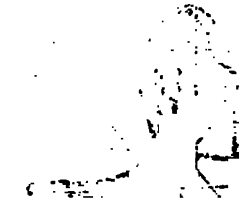
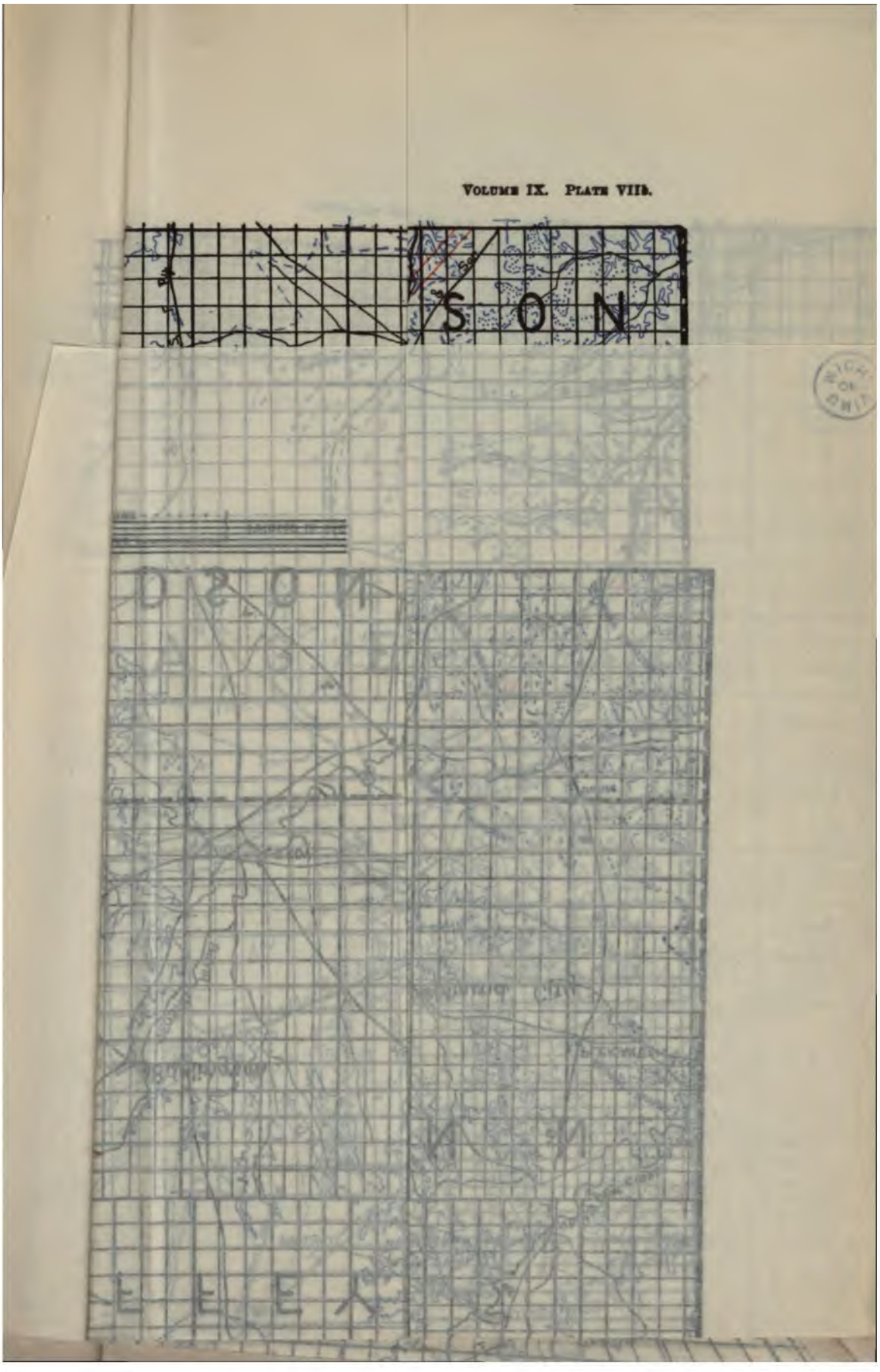




VOLUME IX. PLATE VIIb.



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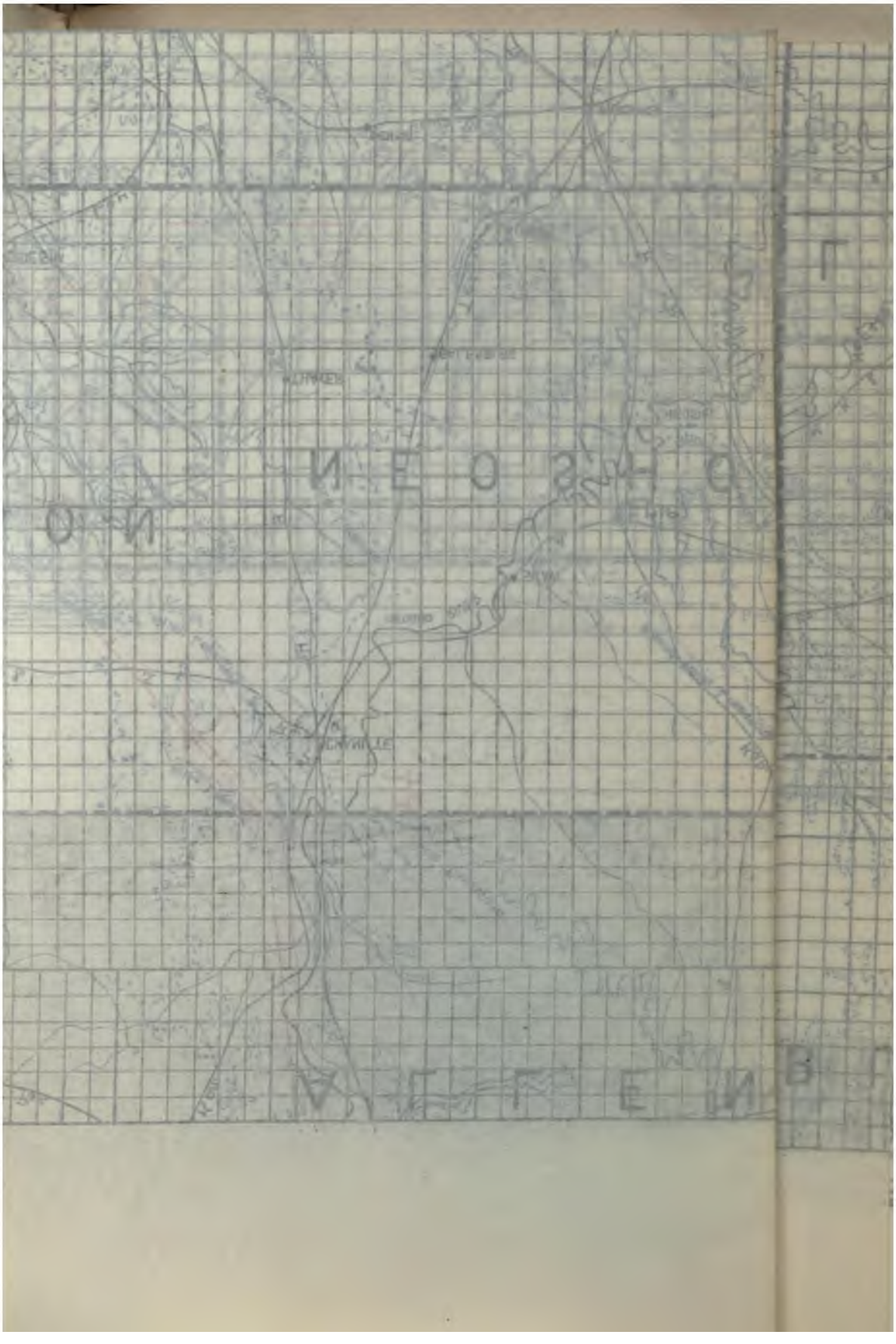

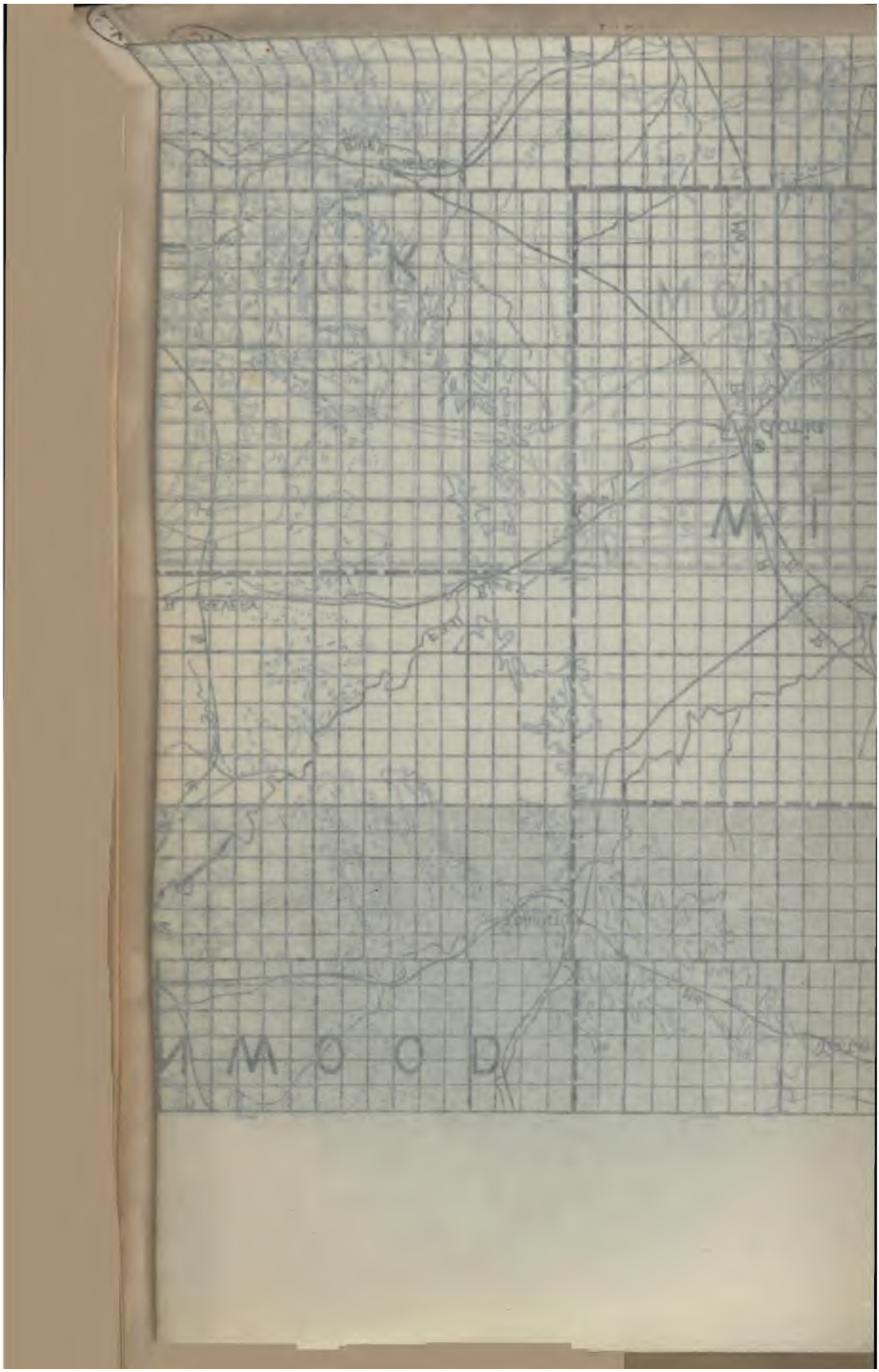

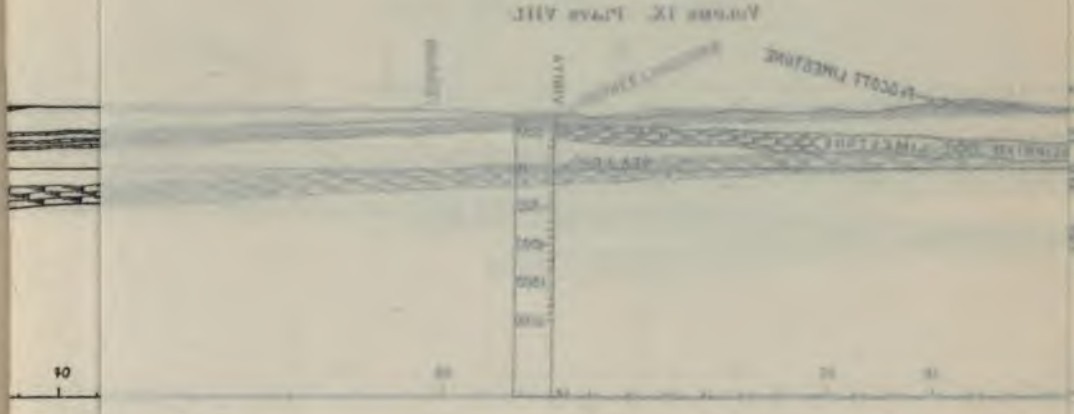

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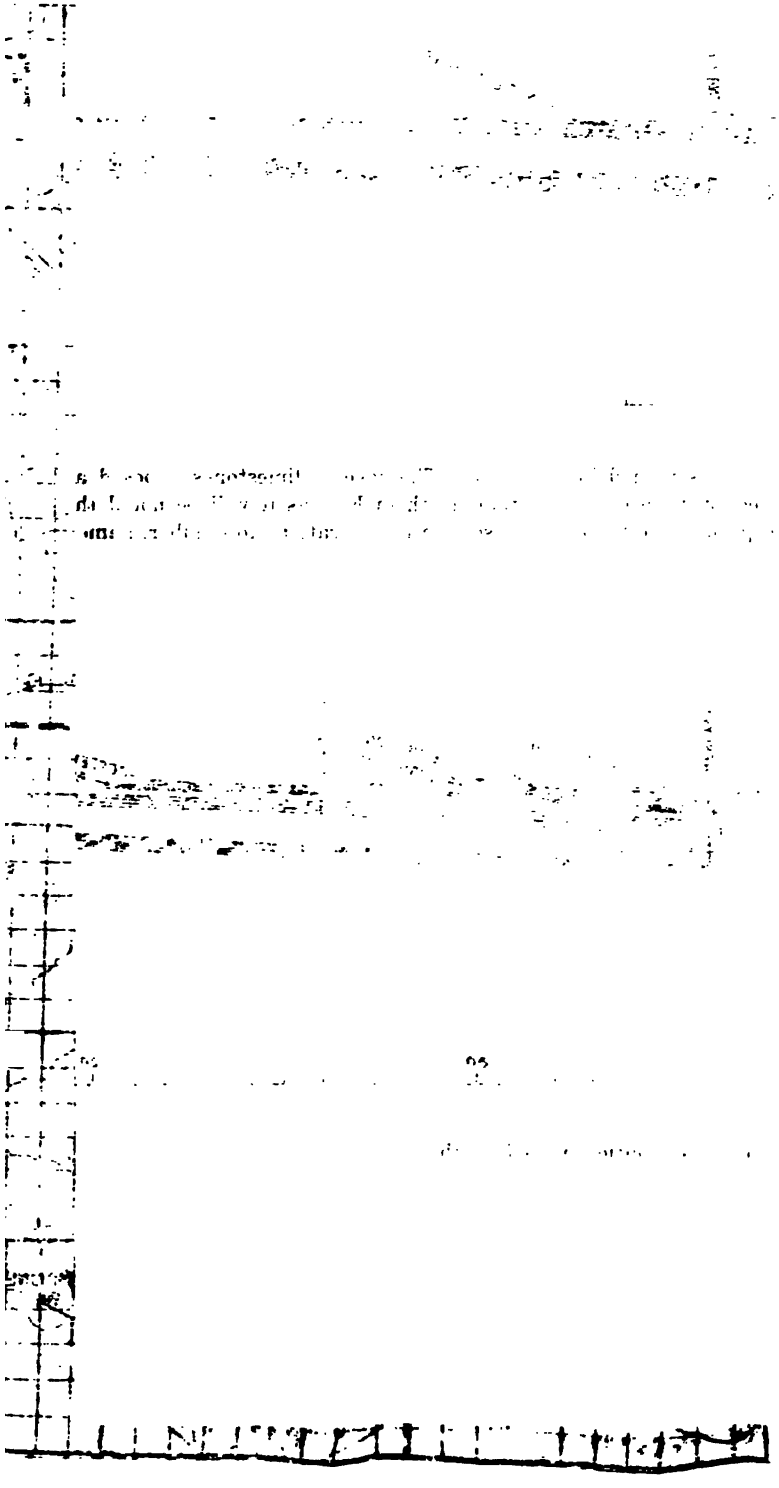

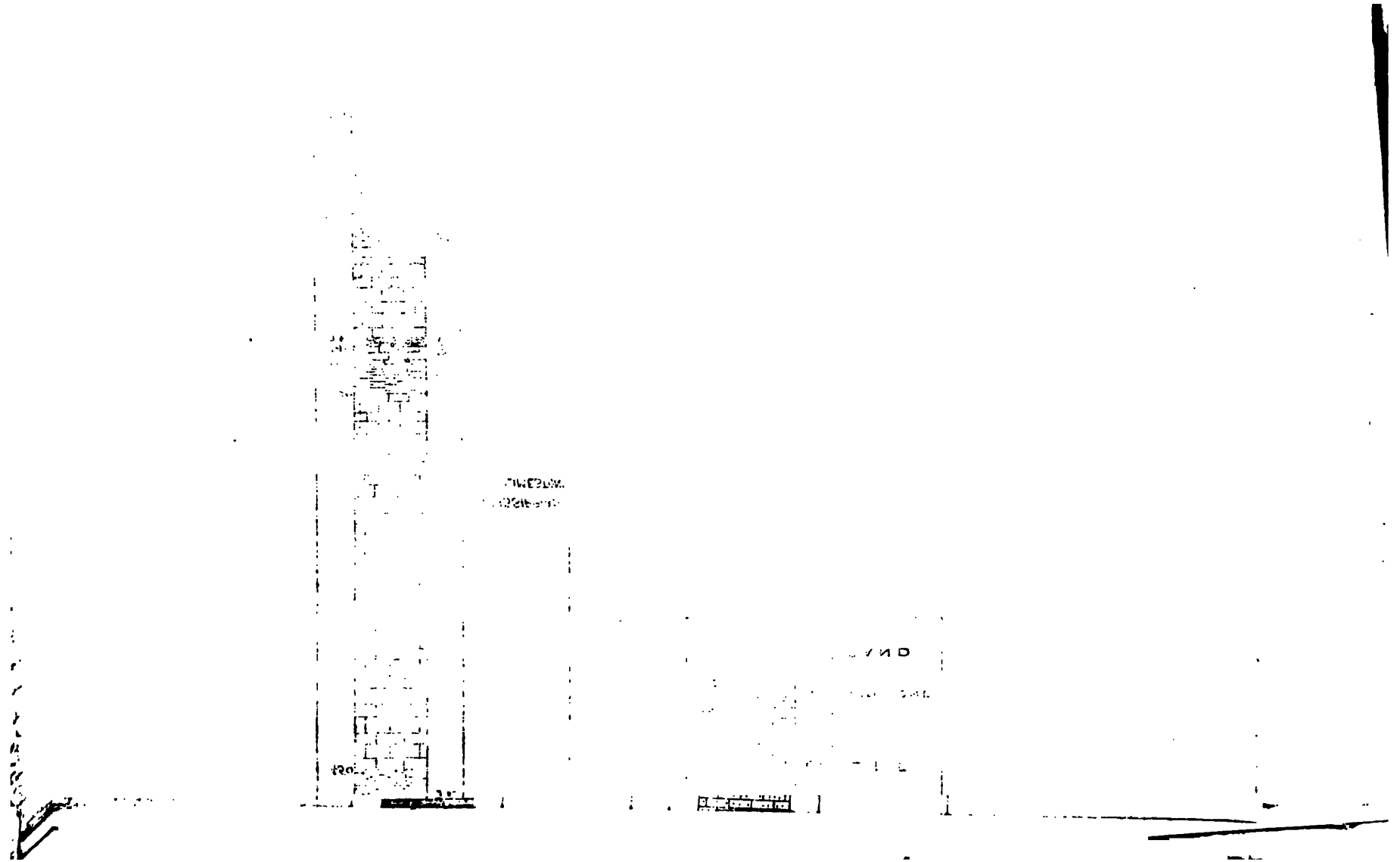

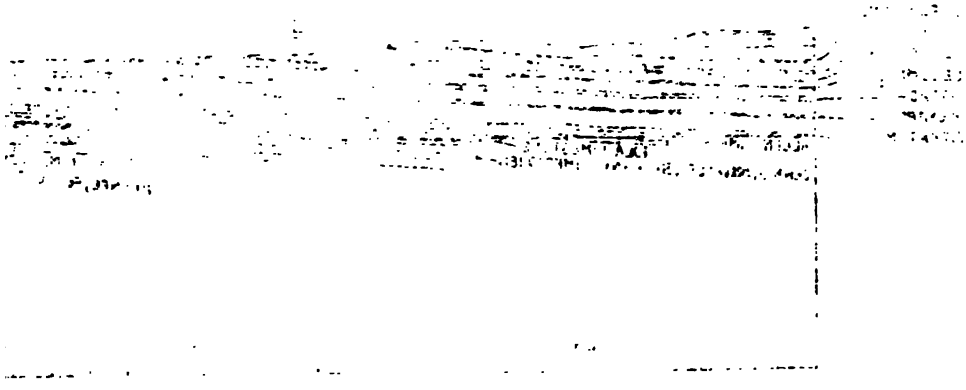

VARYING SLIGHTLY IN COLOR A
GRAINS UP TO 3/4 IN DIAMETE
825
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168

IOLA DEEP WELL

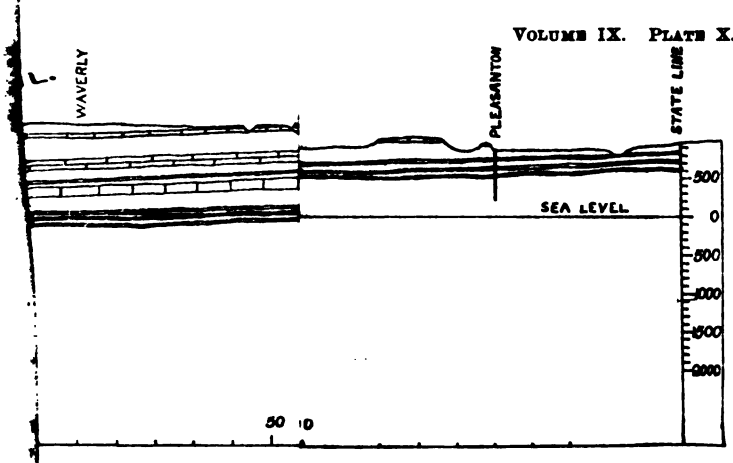

FIG. 1.
Emporia, passing throug
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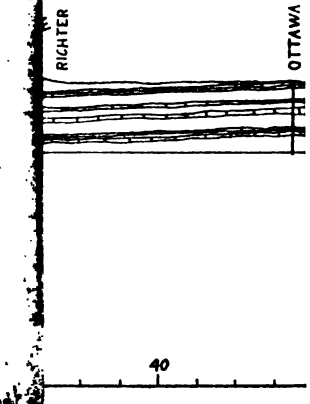

FIG. 2.
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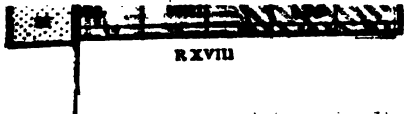
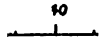


Oil Pipe Lines.

Oil Pipe Lines.



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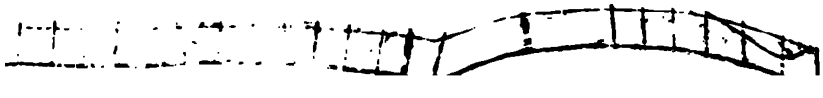

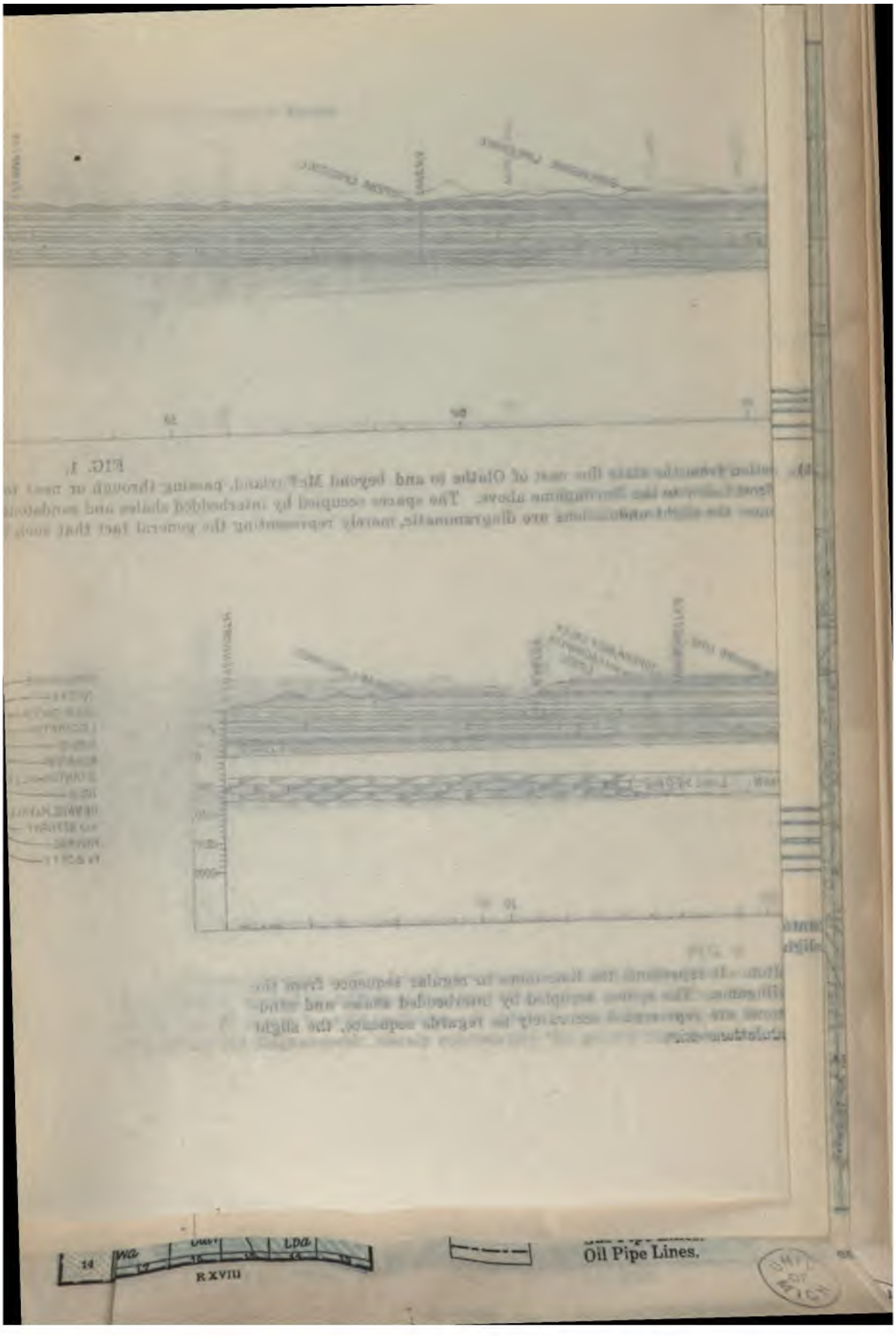
Oil Pipe Lines.

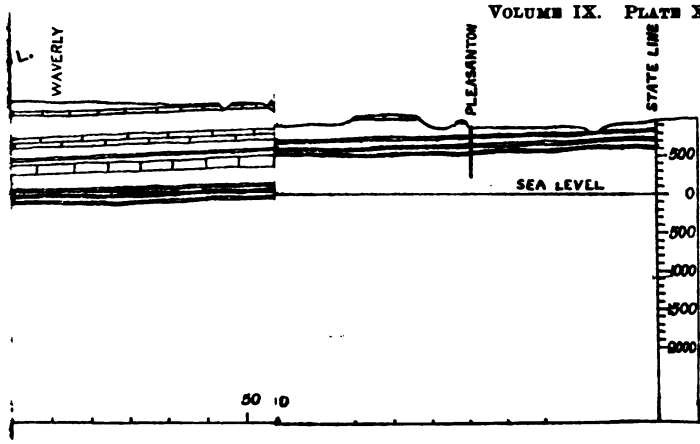

FIG. 1.
Emporia, passing throug
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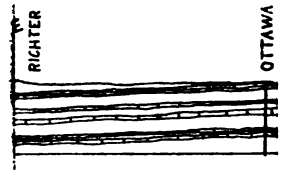

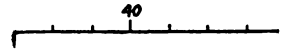

FIG. 2.
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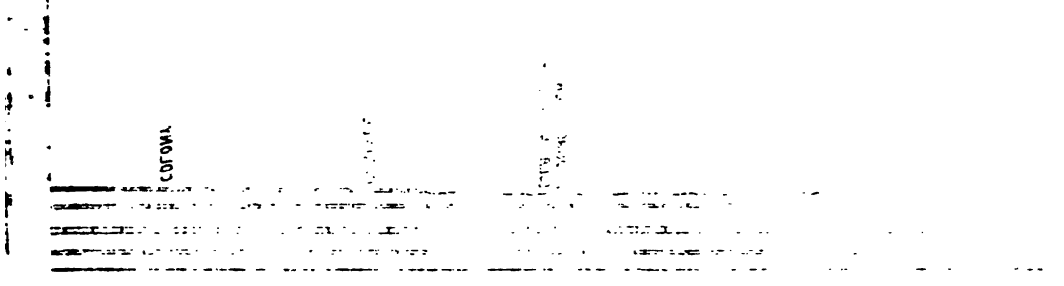
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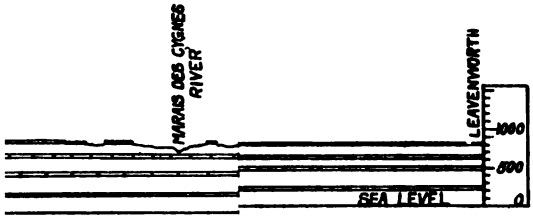
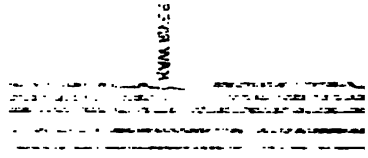
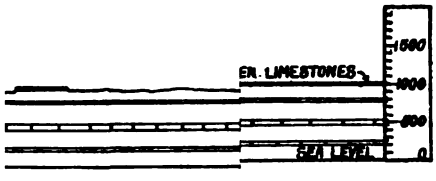
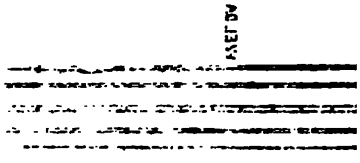
Oil Pipe Lines.

VOLUME IX. PLATE XII.









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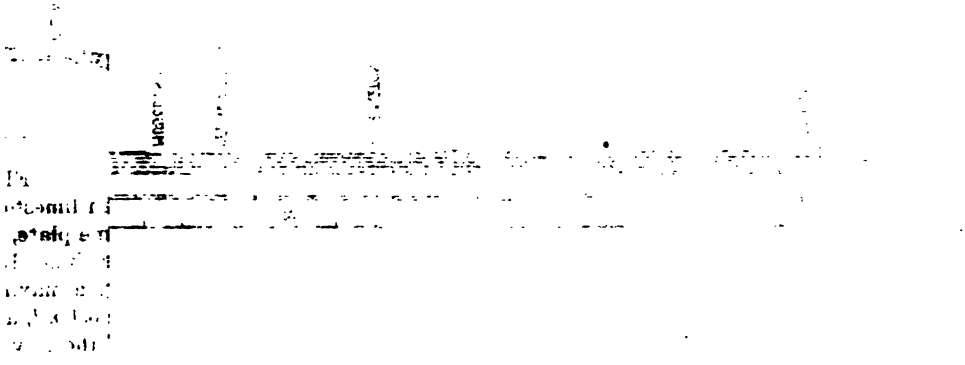
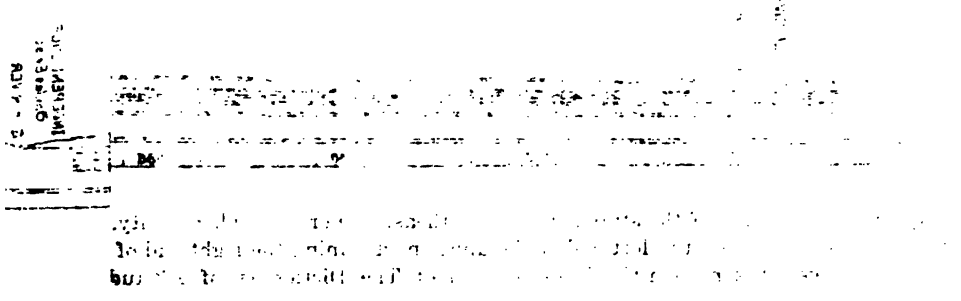
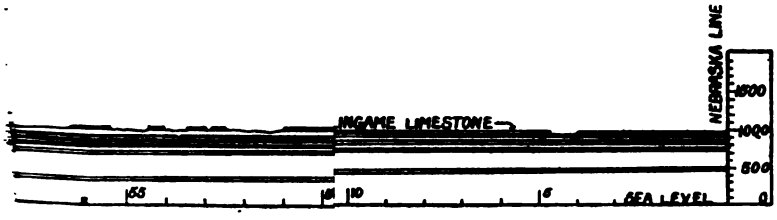
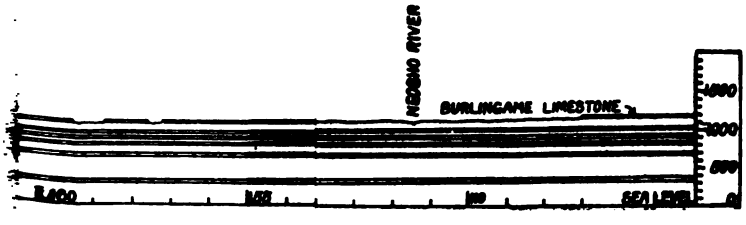




VOLUME IX. PLATE XIII.





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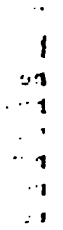
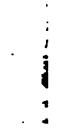
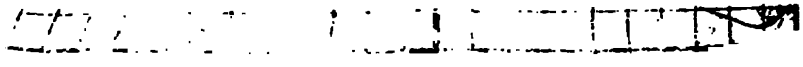
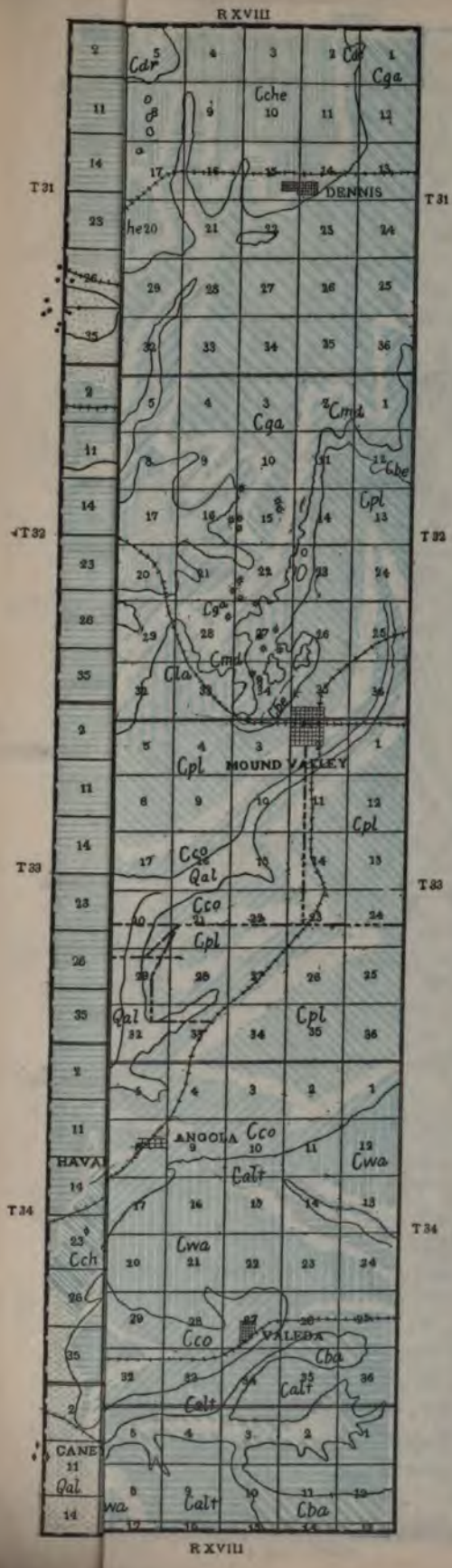
Gas Pipe Lines.
Oil Pipe Lines.









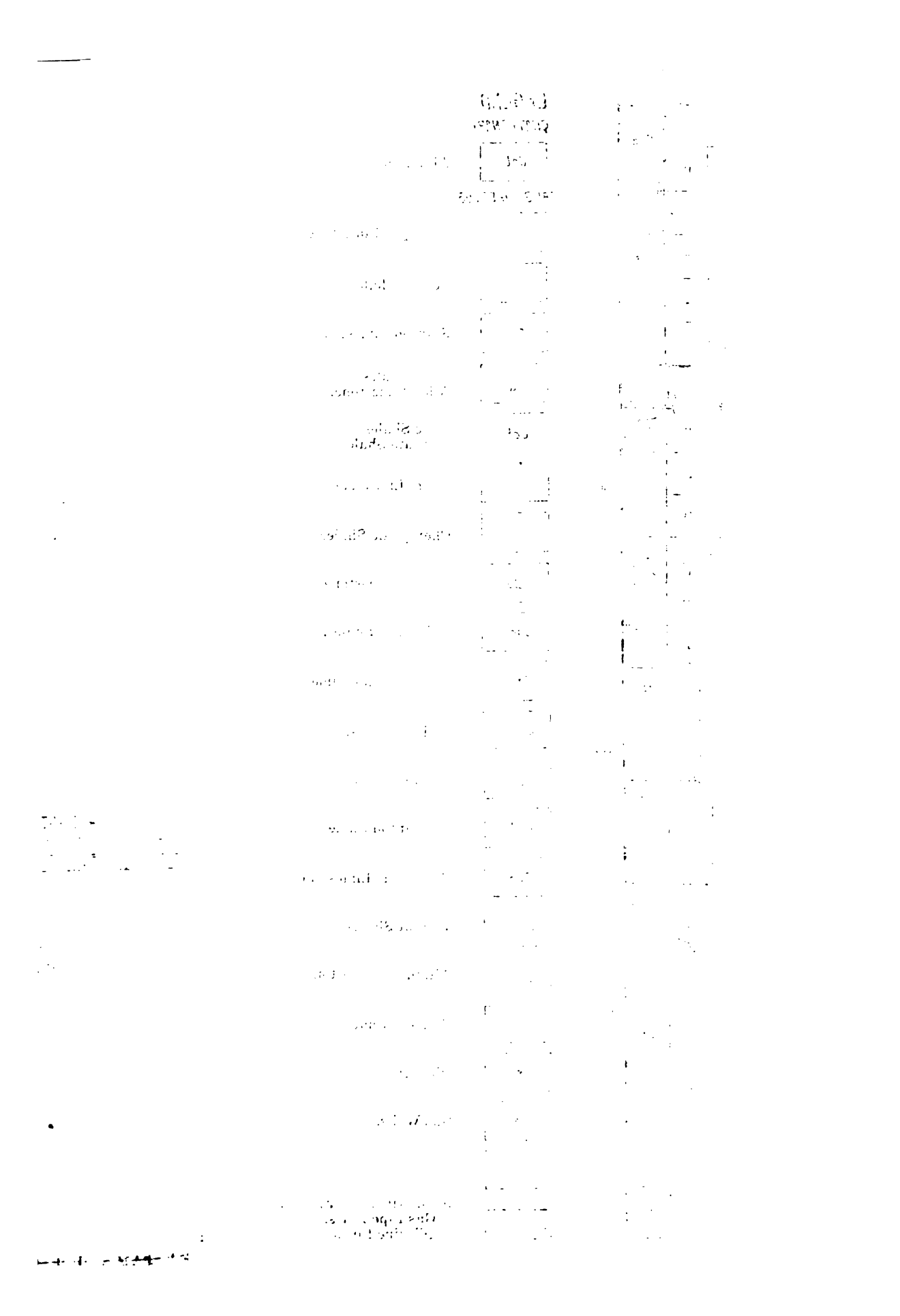
LEGEND

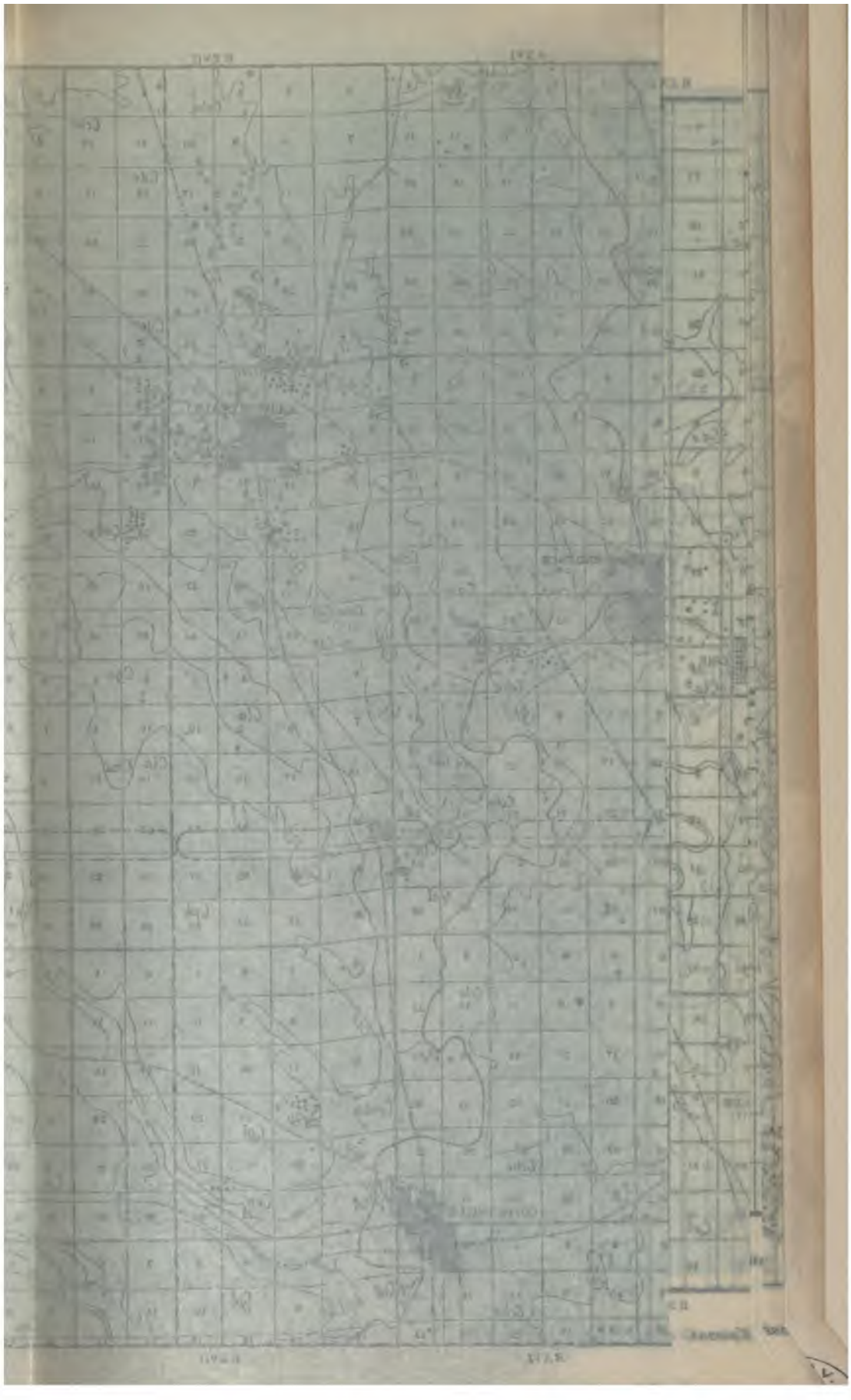
QUATERNARY

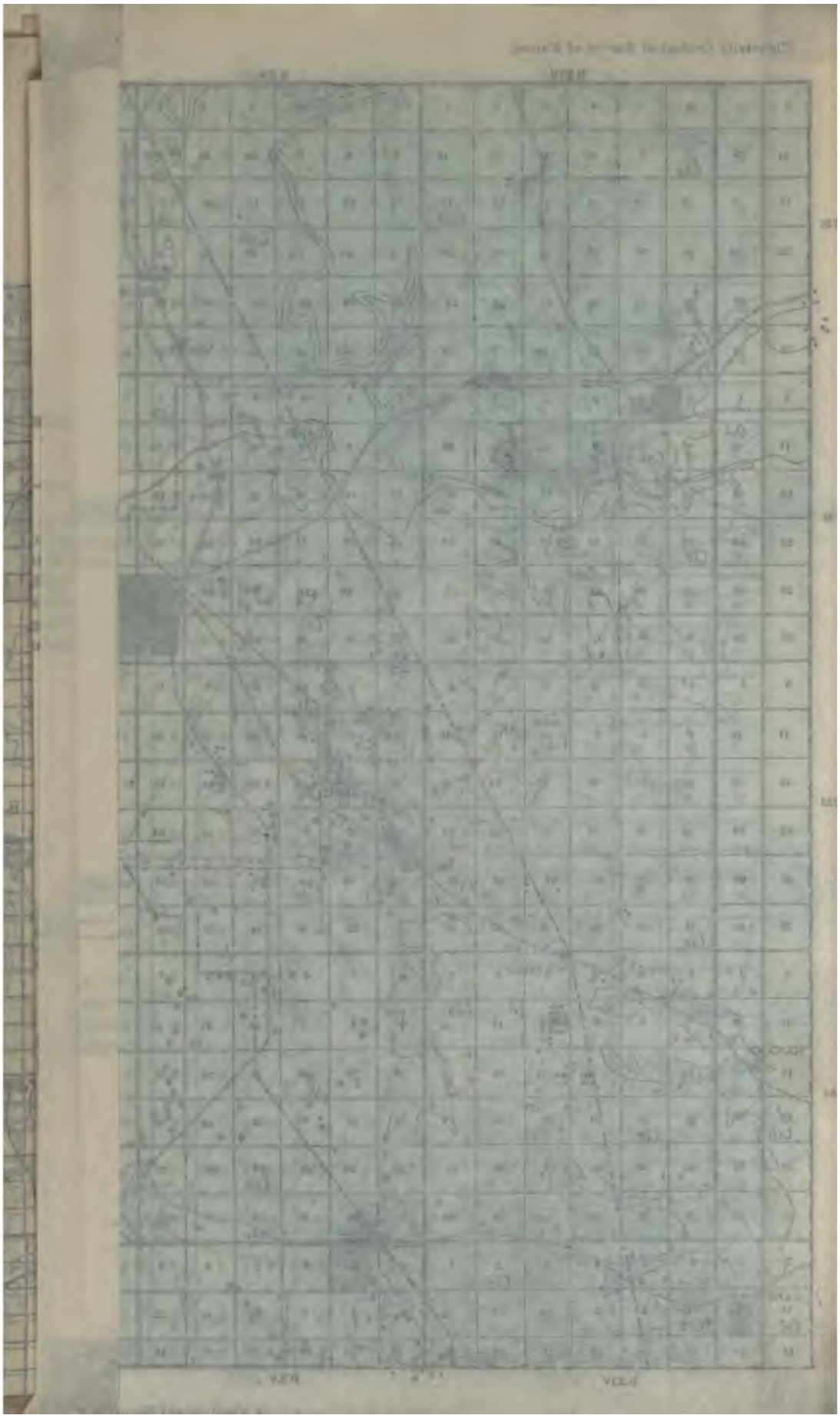
Qal	Alluvium.

CARBONIFEROUS

Cki	Kickapoo Limestone.
Cle	Le Roy Shales.
Cst	Stanton Limestone.
Calh	Vilas Shales. Allen Limestone.
Cch	Lane Shales. Chanute Shales.
Cdr	Drum Limestone.
Cche	Cherryvale Shales.
Cde	Dennis Limestone.
Cga	Galesburg Shales.
Cmd	Mound Valley Limestone.
Cla	Ladore Shales.
Cbe	Bethany Limestone.
Cpl	Pleasanton Shales.
Cco	Coffeyville Limestone.
Cwa	Walnut Shales.
Calt	Altamont Limestone.
Cba	Bandera Shales.
•	Oil Wells.
✻	Gas Wells.
ϕ	Dry Holes.
	Approximate location of Gas Pipe Lines. Oil Pipe Lines.







LEGEND

QUATERNARY

Qal Alluvium.

CRETACEOUS

Kw Wyes Shales.

Kla Allen Limestone.

Kca Cane Shales.

Kfa Iola Limestone.

Kch Chanute Shales.

Kdu Drum Limestone.

Kcha Cherryvale Shales.

Kda Dennis Limestone.

Kgs Galesburg Shales.

Kmv Mound Valley Limestone.

Kla Ladore Shales.

Kbe Bethany Limestone.

Kpa Pleasanton Shales.

Kwa Wabaunsee Shales.

Kla Altamont Limestone.

Kbr Brandon Shales.

Kpa Topeka Limestone.

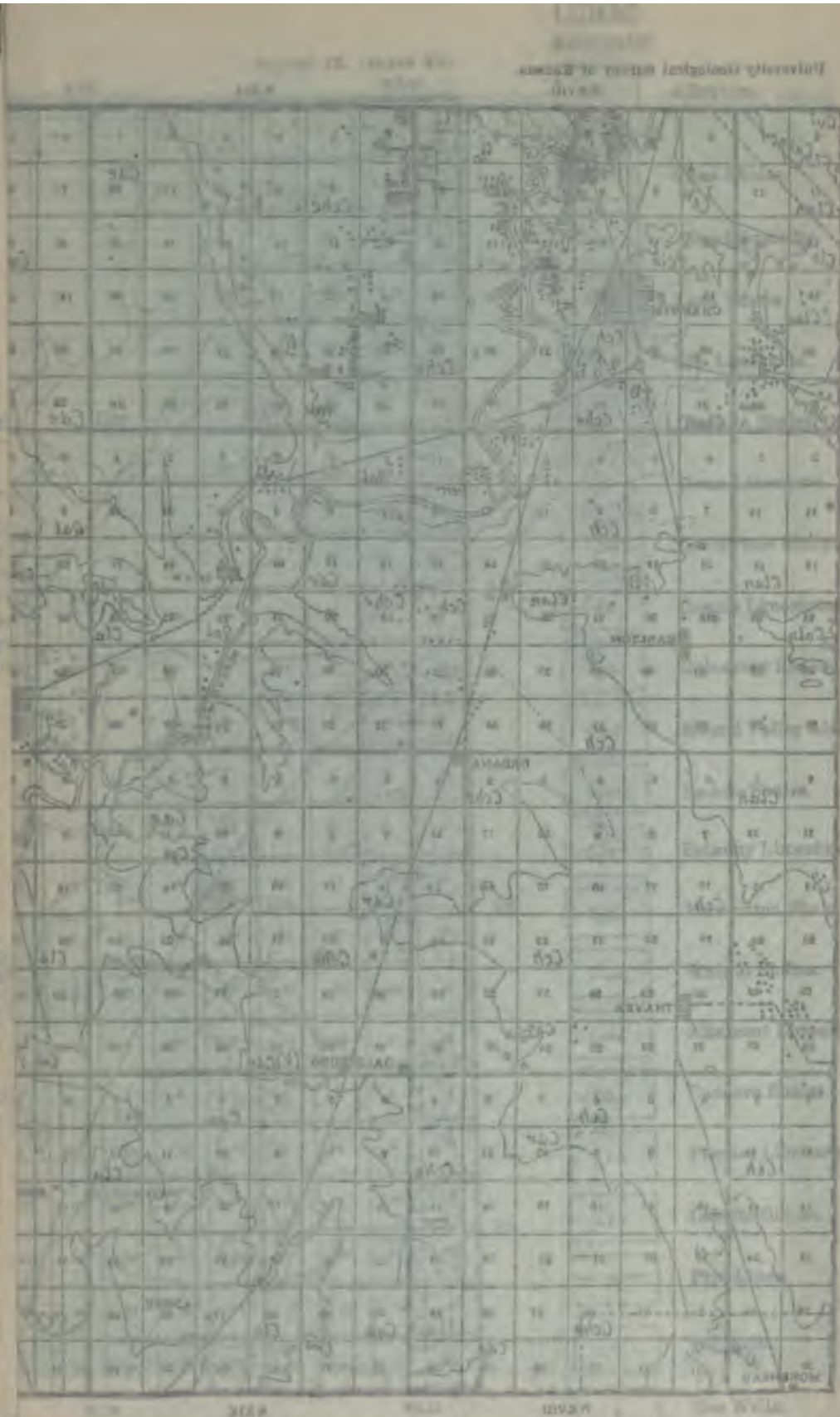
Kla Lecompton Shales.

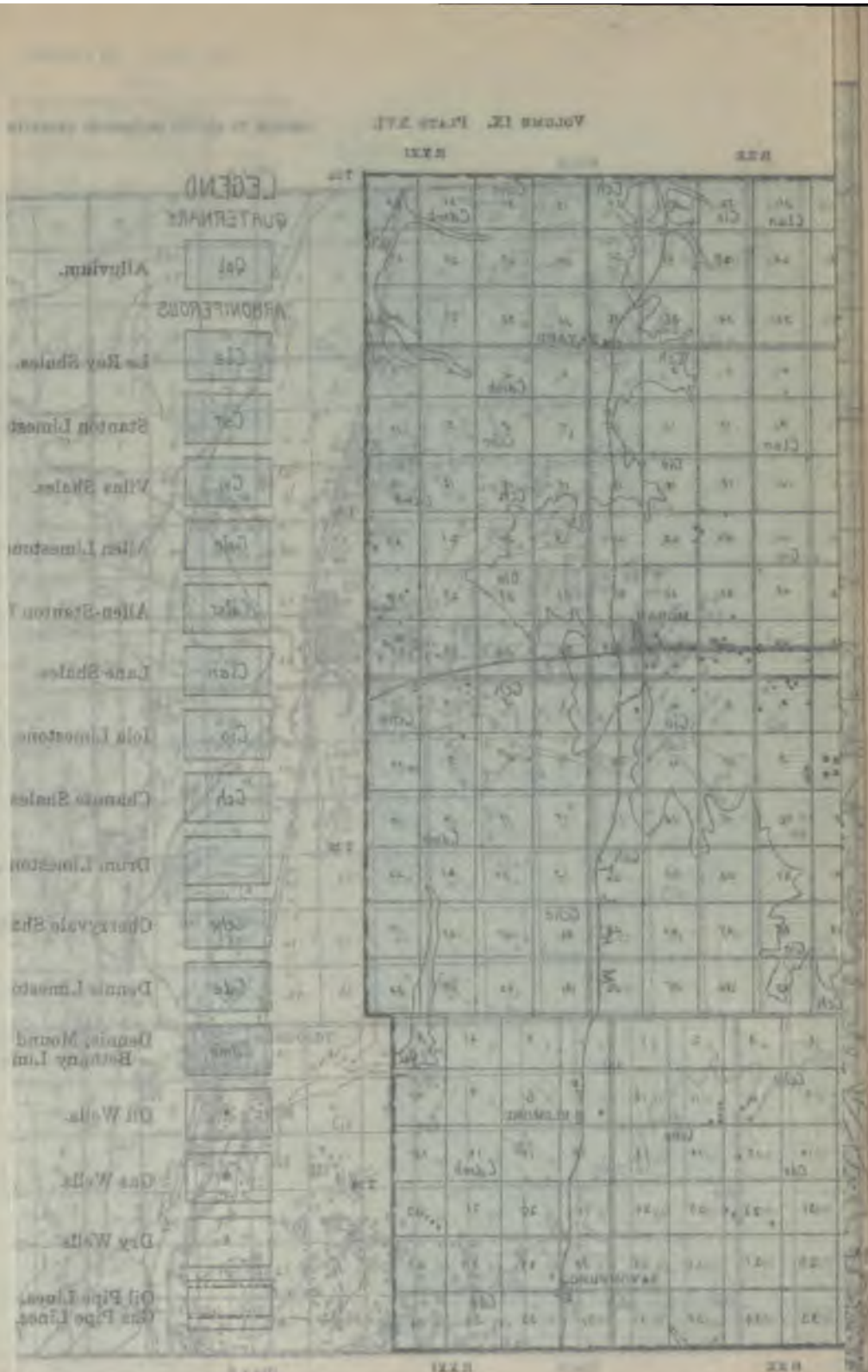
Kp Pre Lime.

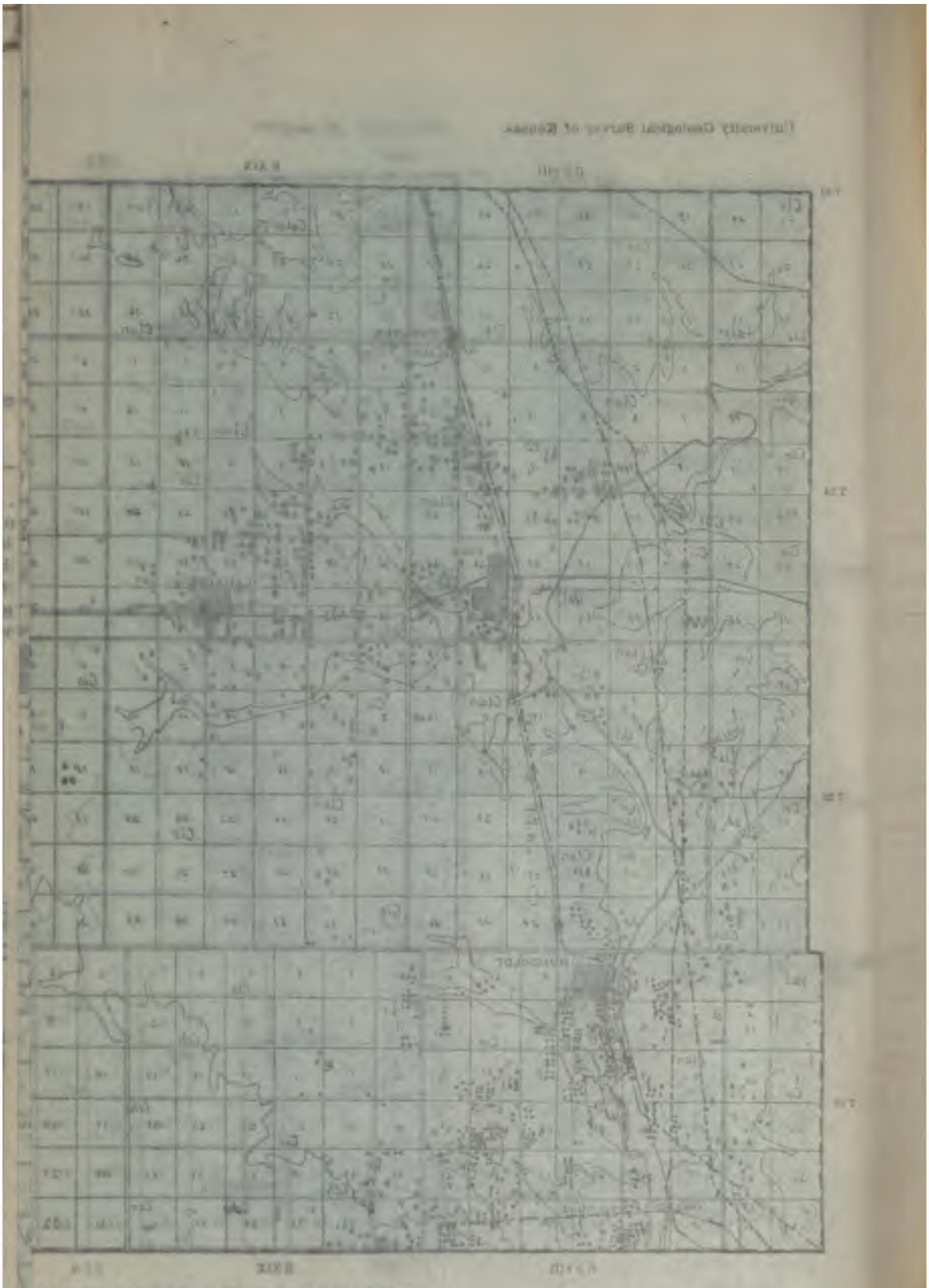
Oil Wells.

Gas Wells.

Dry Wells.







A Geological Surface Map of Allen County, Ka

LEGEND

Quaternary

Qal	Alluvium.

Carboniferous

Calst	Stanton-Allen Limestones.
Clan	Lane Shales.
Cio	Iola Limestone.
Cch	Chanute Shales.
Cdr	Drum Limestone.
Cche	Cherryvale Shales.
Cdmb	Dennis, Mound Valley and Bethany Limestones.
Cpl	Pleasanton Shales.
•	Oil Wells.
◊	Dry Wells.
☼	Gas Wells.
---·--·--·	Oil Pipe Lines.

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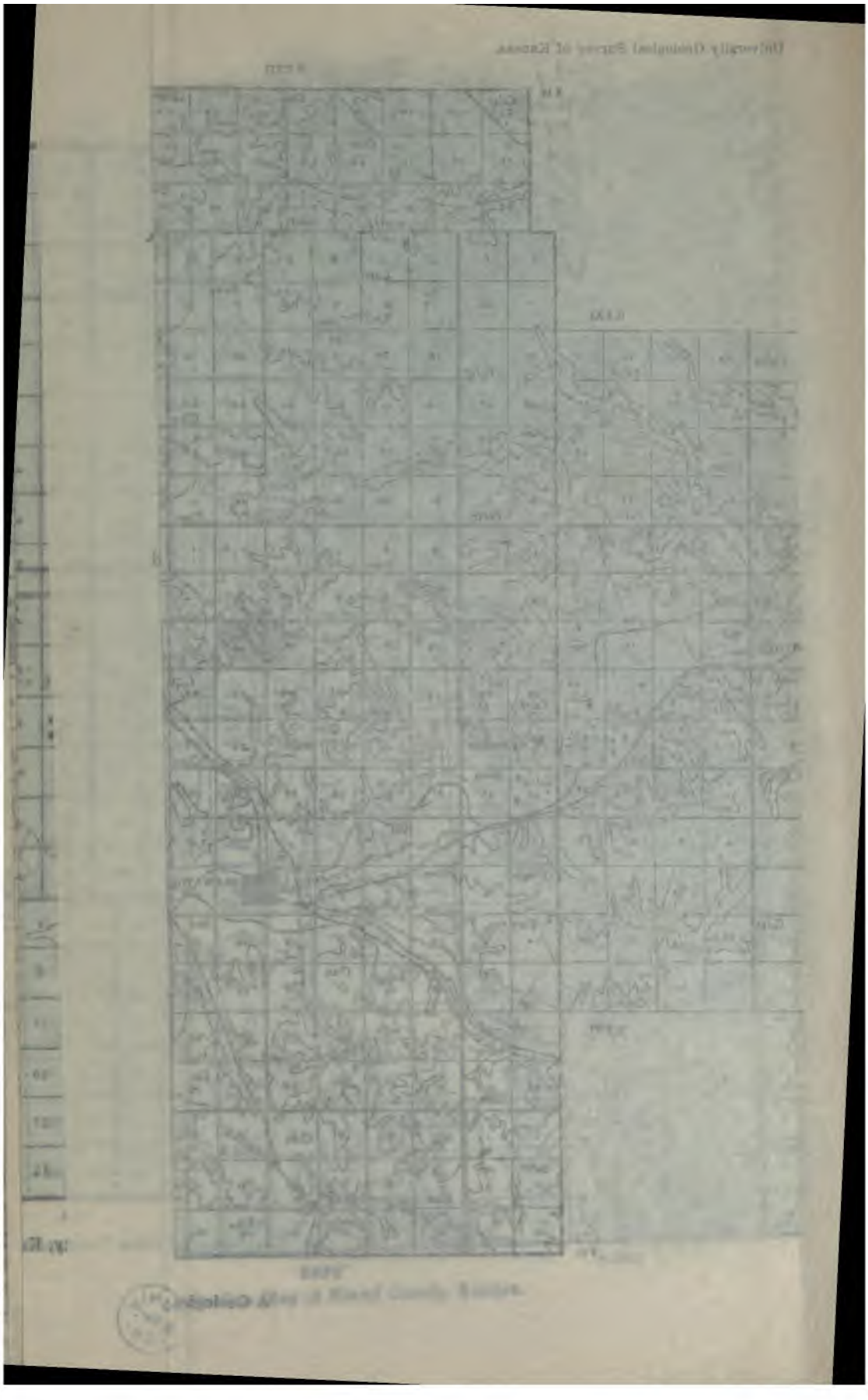
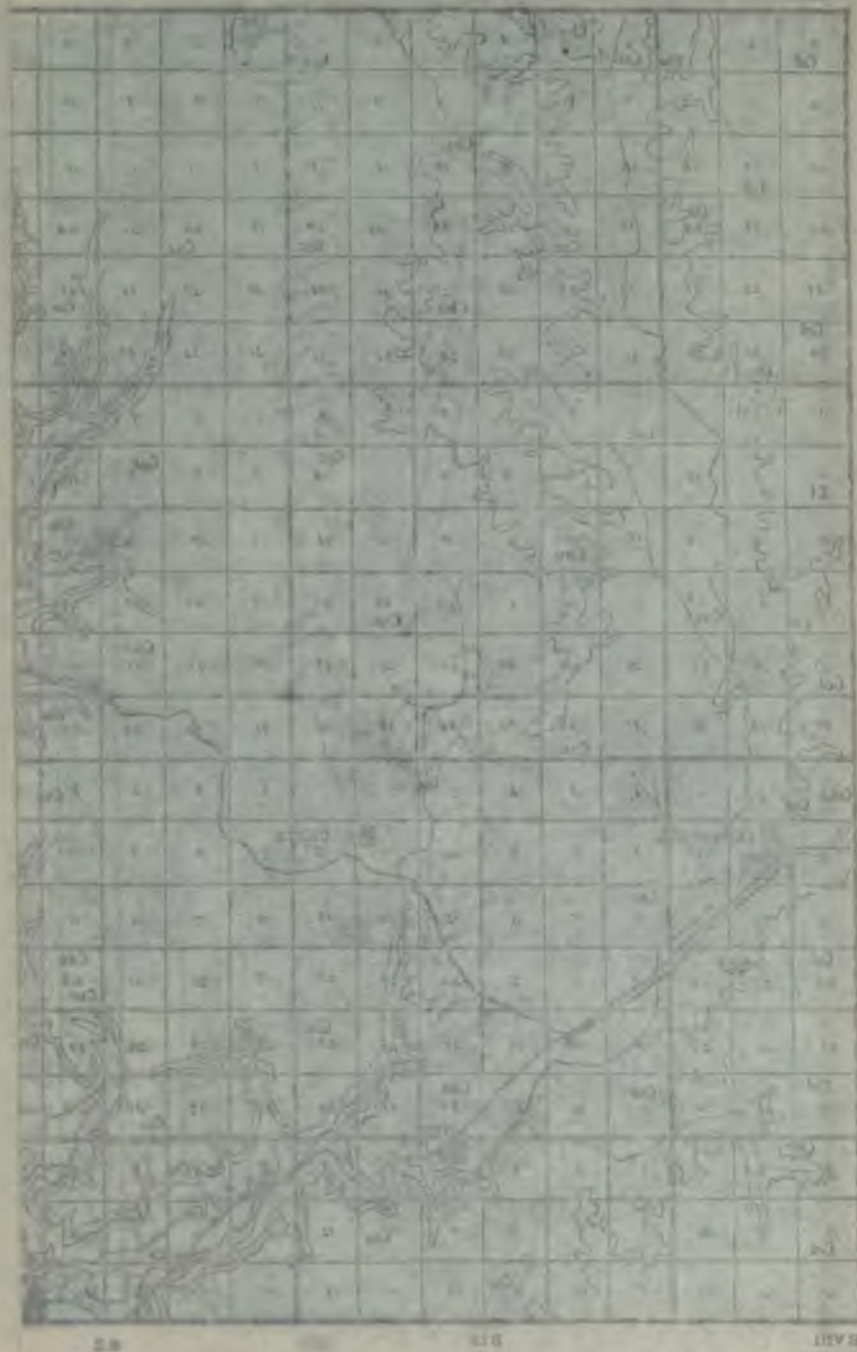


An Oil Well spouting after being shot. Sagamore Oil Company, Lot 66, Osage Lands, Okla.



An Oil Well spouting after being shot. Sagamore Oil Company, Lot 66, Osage Lands, Okla.

An Oil Well spouting after being shot. Delokee, No. 8.
Near Bartlesville, Okla.

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An Oil Well spouting after being shot. Delokee, No. 8.
Near Bartlesville, Okla.

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An Oil Well spouting after being shot. In North Field, Chanute, Kan.

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An Oil Well spouting after being shot. Southwestern No. 6.
Two and one-half miles north of Chanute, Kan.

An Oil Well spouting after being shot. In the East Trend, Chanute, Kan.

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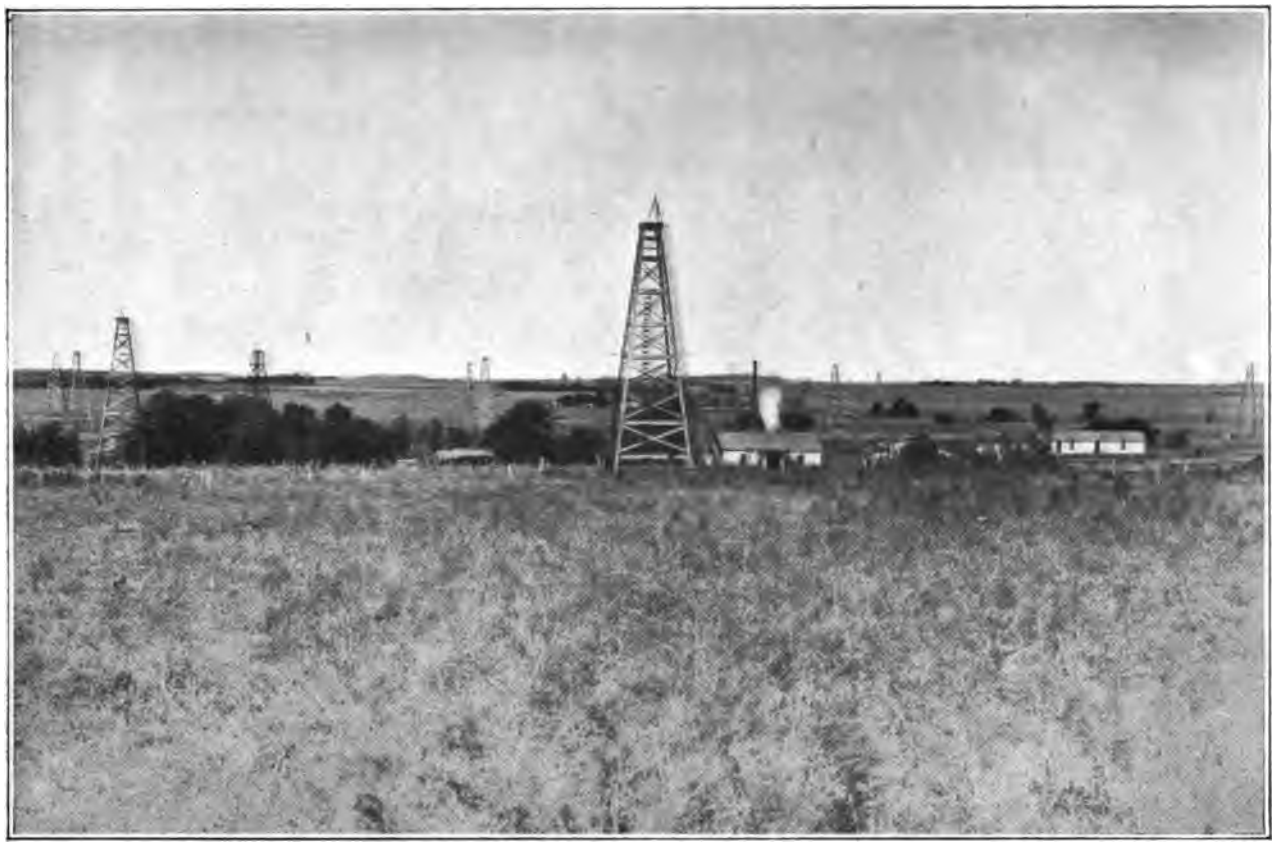
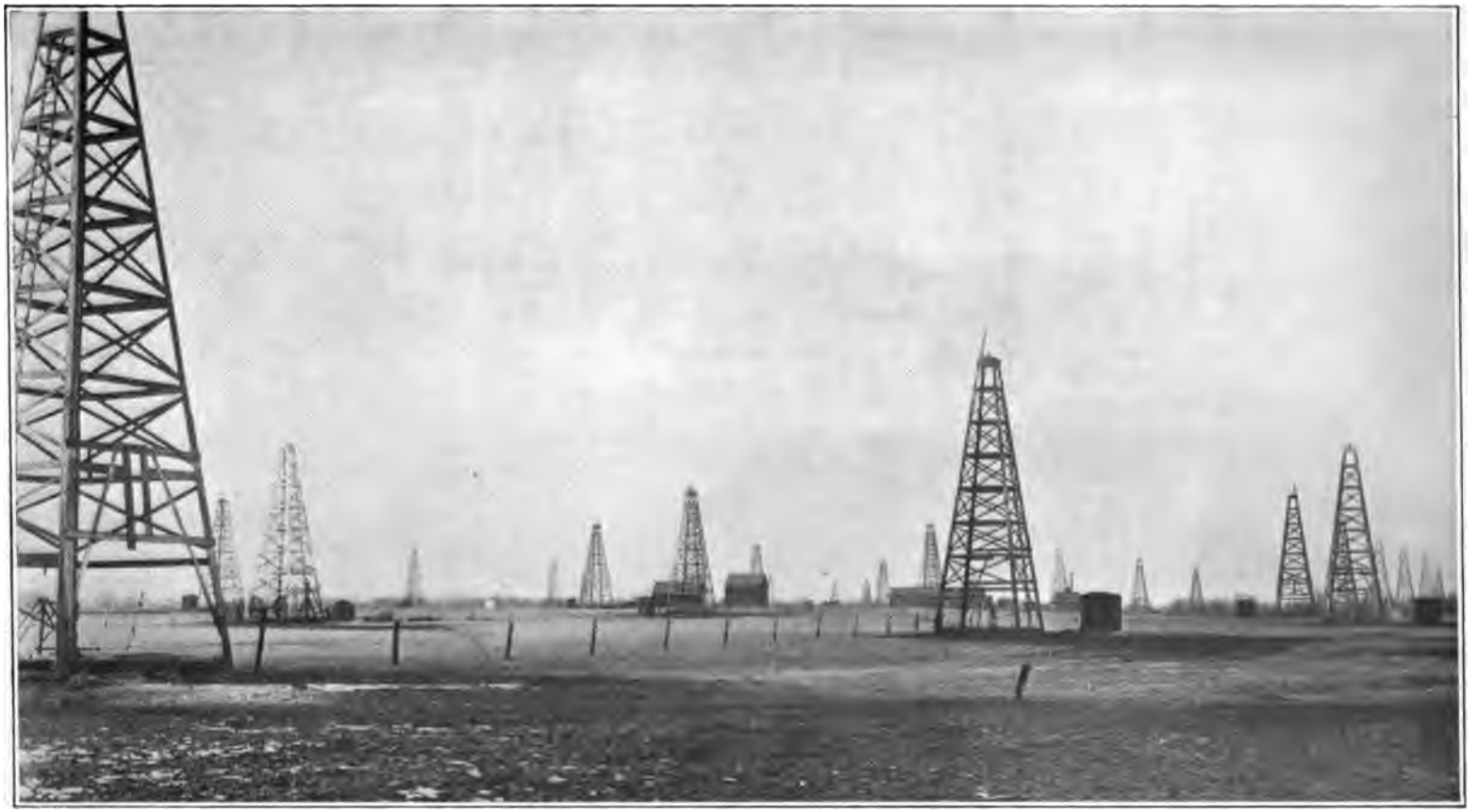
An Oil Well spouting from pressure of Natural Gas. Near Chanute, Kan.

An Oil Well spouting from pressure of Natural Gas. Near Chanute, Kan.

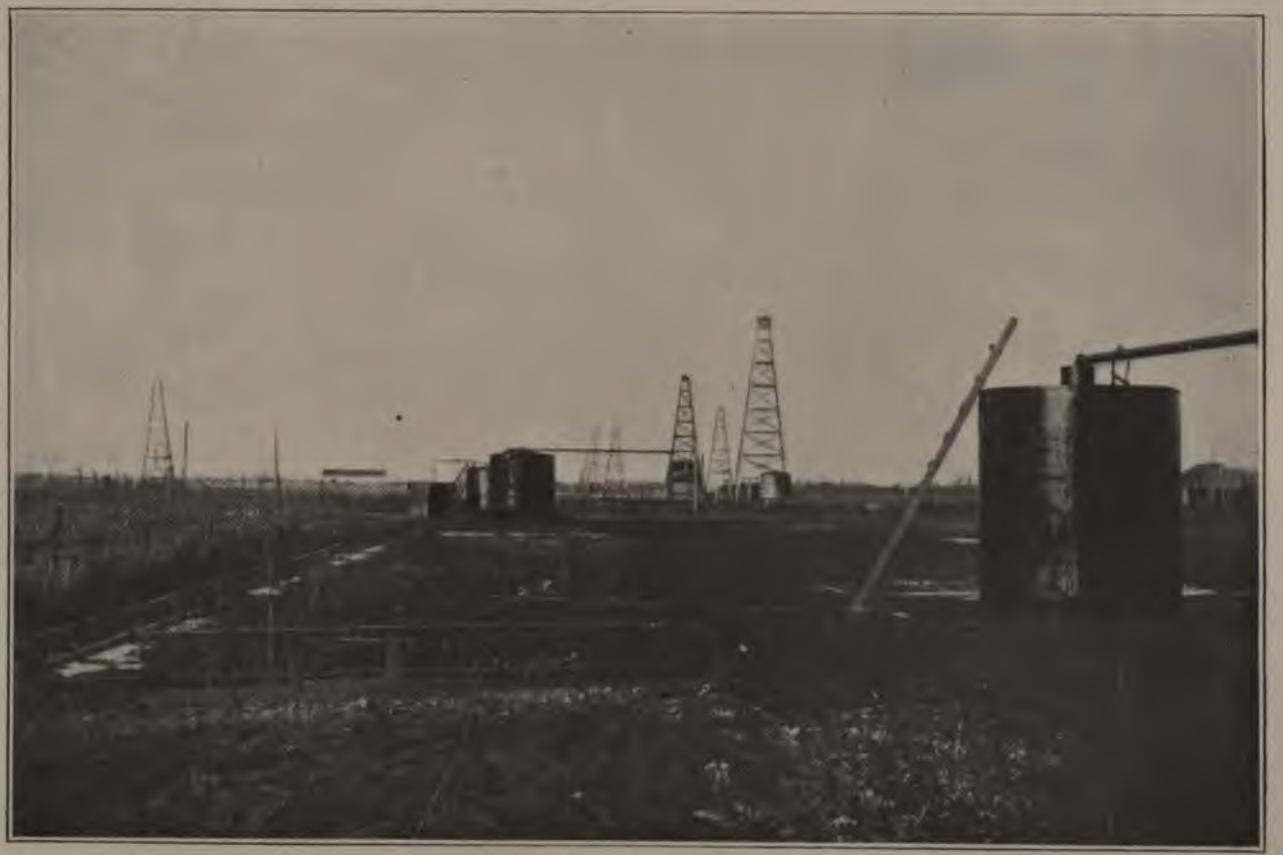


A Pumping Station and field of Derricks. East Trend, Chanute, Kan.



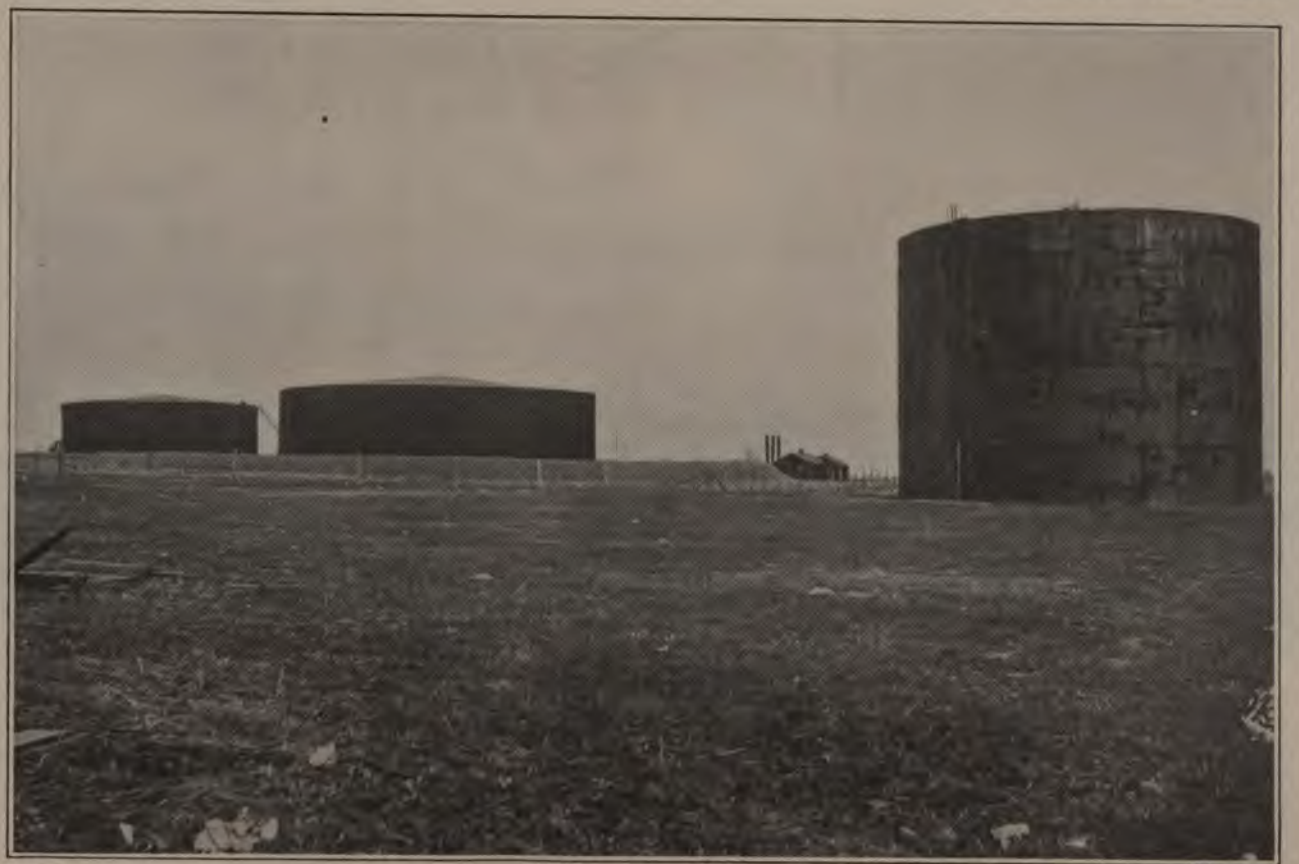
A field of Derricks. Barker Oil Company's land, two and one-half miles north of Chanute, Kan.

A field of Tanks and Derricks. Webber Pool, near Bartlesville, Okla.



A field of Tanks and Derricks. North of Chanute, Kan.

Pumping an Oil Well with compressed air, on the I. N. Knapp land, Chanute, Kan.



A Tank Farm and Pumping Station. Chanute, Kan.

A Tank Farm. Copan, Okla.

Building a 35,000-barrel Oil Tank.

Starting a 35,000-barrel Oil Tank.

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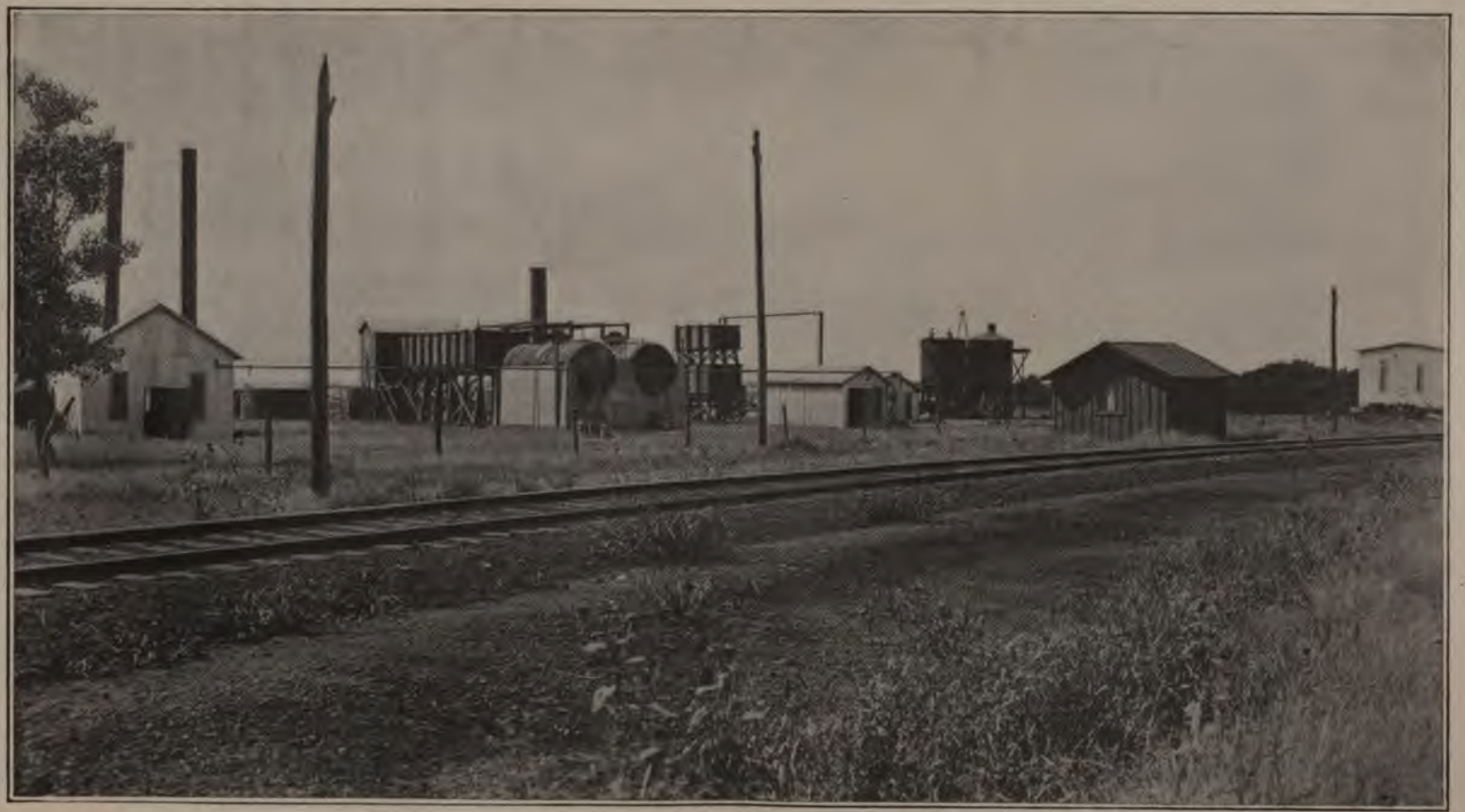

Plant of Kansas Refining Company in process of construction. Chanute, Kan.

Kansas Coöperative Refining Company's Plant, Chanute, Kan.

Chanute Refining Company's Plant, Chanute, Kan.

The famous Caney Gas Well on fire. Six miles southeast of Caney, Kan., in Oklahoma.

FIG. 1. Center of cut east of Grand Summit, showing main fossil horizon in lower part of Neosho formation.

FIG. 2. Showing Neva Limestone in cut south of Dexter, looking north.

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CHAPTER IV.

DETAILED GEOLOGY OF OIL AND GAS.[104]

By ERASMUS HAWORTH.

OIL and gas are found in rocks of many different geological ages. In Indiana and western Ohio they are in the Trenton limestone, a member of the Lower Silurian or Ordovician. From here upwards the Pleistocene or recent rocks of every geological age, at one place or another, have been productive of oil or gas. It is difficult, in fact, to decide where the greatest production occurs. In the Appalachian region it is the Carboniferous and Devonian; in the Midcontinental field the Carboniferous; at Corsicana, Tex., and Florence, Colo., the Cretaceous. In different places in Wyoming oil is found in formations ranging from the Permian to the Upper Cretaceous. In California the Tertiary seems to be the most productive. At Beaumont, Tex., and adjacent parts of Louisiana, the formations are Pleistocene or recent, and in the wonderful oil-fields of Russia on the western shores of the Caspian Sea oil is found in sands scarcely cemented together, belonging to the Oligocene and Miocene Tertiary.

In Kansas and other parts of the Midcontinental field, as far as developments have shown up to July 1, 1908, both oil and gas are confined to the Coal Measures, with the exception of the small wells in the immediate vicinity of Muskogee, which apparently draw their supply from below the Mississippian.

Oil and gas are most generally obtained in sandstone, but by no means always. Apparently the essential function of a sandstone in this connection is to supply an opening or void which may serve as a cistern or reservoir. Probably other rocks

104. In this undertaking extracts will be made whenever desired from Bulletin 238, U. S. G. S., because the detailed geology of the Iola quadrangle area was written by Haworth, and drawings for the same were made in this office under his immediate direction, the subjects being chosen by him, although they appear in the above-named bulletin as though they resulted from the labors of another. This error, or whatever it may be called, was due to the manuscript passing out of Haworth's hands and supervision of its publication controlled by the party under whose name it appears in Bulletin 238.

would do just as well were they equally porous. In the great Trenton limestone pools the productive rock is a limestone. Here, however, nature has performed differently from the ordinary, and by a system of metamorphism has altered the Trenton limestone, making it into a rock as porous as many sandstones. Likewise, a shale-bed, if sufficiently compact, may, by earth movements, have fissures produced in it which become productive reservoirs. Soft shale cannot be productive to any considerable extent because fissures produced in it will not remain open, and therefore the necessary underground reservoir would not be obtainable. But where shale-beds have been metamorphosed and hardened they may become productive, provided other necessary conditions obtain. This is illustrated notably at Florence, Colo., and in different places throughout the California oil-fields, where heavy shale-beds have been metamorphosed and fissured and filled with oil.

Seven colored geological maps are herewith included, covering seven different counties, on which the several areas occupied by the different geological formations are represented in appropriate color and design. In studying the detailed geology of eastern Kansas one should examine these maps with care in connection with plate III, an ideal vertical section of the Kansas Coal Measures; plate VII*a*, VII*b* and VII*c*, a surface map in which limestone outcroppings alone are marked in appropriate colors; plates VIII to XIII, inclusive, which represent vertical sections across the east end of the state in different directions, and, finally, the various plates showing records of wells drilled in the oil-fields, which well records are here represented in as great number as seems at all desirable in order to give a complete exposition of the entire underground conditions of this portion of the state. The counties represented by the colored maps are as follows: Plate XIV, Montgomery county; plate XV, Neosho county; plate XVI, Allen county; plate XVII, Miami county; plate XVIII, Chautauqua county; plate XIX, Wilson county, and plate XX, Woodson county.

At first glance the reader unaccustomed to such maps may think they are confusing, but a little care will bring everything out in a clear manner. The line of demarcation between the more prominent formations is indicated by a black line. For some of the lesser ones, however, no line whatever is drawn, the boundary line being implied by a difference in the colored shading. One should think of each individual formation as be-

ing a plain or shelf dipping gently to the west and occupying a position intermediate between others above and below. The surface is modified by erosion, with hills here, valleys there, streams, channels, mounds and other irregularities interfering, so that any given formation, particularly a limestone formation, is liable to have outliers some distance beyond the eastern edge. This is illustrated on the Montgomery county map by the Stanton limestone, with an outlier covering Table Mound, northwest of Independence, and Walker Mound, southwest of Independence. Likewise, a given formation has projections extending westward along a stream valley where the stream has cut through the overlying formations, exposing the underlying one farther to the west than is the ordinary, as is well illustrated by the Stanton limestone extending westward up a tributary of Elk river to beyond opposite Elk Falls, and particularly the same limestone extending westward from Allen county across into Woodson county.

These maps have represented on them the oil-wells, gas-wells and dry holes, corrected up to about September, 1907. Possibly a few wells were omitted, but it was our endeavor to make them as nearly complete as possible.

The most productive individual horizon in the entire Mid-continental field is that occupied by the Cherokee shales. Practically all the oil and gas from Caney to the east, south and north occur in these shales, although in a few places either oil or gas has been found in overlying formations. The greatest production in Chautauqua county also comes from the same horizon, yet many of the gas-wells and some of the later oil-wells are supplied higher up. Westward, in the vicinity of Longton, Moline and Grenola, and in the gas-fields of Arkansas City, Augusta and Elmdale, the gas occurs probably from 1000 to 1500 feet above the top of the Cherokee shales, although it is not known definitely just how far beneath the surface the Cherokee shales are in that territory. It is evident, therefore, that while the Cherokee shales are the principal producers of oil and gas in this territory, yet almost any and every shale-bed overlying them within the entire Carboniferous area of the state may contain productive sandstones.

Not only this, but occasionally the shales and limestones are small producers. It is a common matter to hear drillers speaking of shale gas, meaning a small but variable amount of gas obtained within shales themselves. Likewise, in rare

cases, limestone is productive, more commonly perhaps in Oklahoma, near Bartlesville, than in Kansas; but these somewhat unusual conditions should not be taken very seriously, as the total amount of oil and gas thus far obtained from shale and limestone aggregates but a small fraction of one per cent. of the total production. This is an important statement, not only from theoretical consideration but also from a practical one. Wells may be drilled here and there in many places, therefore, with a hope of finding oil or gas without being carried to so great a depth as would be necessary were the Cherokee shales the only producers. Thus far in our development no well west of Chautauqua county has been carried to so great a depth, and we are entirely ignorant regarding what the results would be should such a well be drilled. In fact, we have no positive evidence that the Cherokee shales with their included sandstones exist as far west as Winfield, although the presumption is they do.

The shale-beds in the Midcontinental field generally have a great lateral extent. Sand-beds, on the contrary, quite often have a limited lateral extent, or will be limited in one direction more than in another. This is true to so great an extent that sandstone horizons are unreliable as stratigraphic individuals for the purpose of general stratigraphic discussions. Therefore, in previous pages and in those to follow, it is considered desirable to speak of productive sand-beds as being contained within certain shale-beds and the shale-beds alternating with limestone beds. The most extensive and continuous sandstone horizon in this part of Kansas is the Chautauqua sandstone, lying within the Lawrence shales. In places these sandstones are continuous for many miles, but by no means as extensively or regularly as the shale-beds including them. In northern Oklahoma other sandstones sometimes have a comparatively great continuity, such as the sandstone capping the hills west of Bartlesville and extending southward beyond Tulsa and northward throughout Chautauqua county, reaching east into portions of Montgomery county. The drill has revealed a similar set of conditions for underground sandstone. Here a sandstone occurs in comparative purity and satisfactory thickness, while a few miles away it may be entirely wanting. A careful study of surface conditions along the eastern outcropping of every shale-bed of considerable size in the entire field reveals the same conditions.

The sandstones generally are of limited extent laterally and grade into shales in every direction. Sometimes they grade into shales when followed along their outcrop, so that a bed which is sandstone at one place is a shale at another. The same variation that is found along the strike may be expected along the dip, and accordingly shales occurring underground and encountered in drilling wells show such variations in lithology that no definite sandstone horizons can be differentiated.

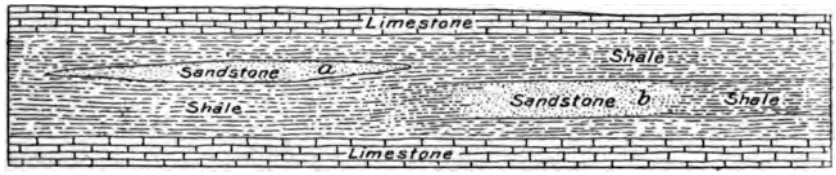

FIG. 2. Diagram showing gradations of sandstone into shale.

Figure 2 is an ideal sketch of the relation of sandstone contained in a shale formation. In this figure the sandstone lettered *a* is lenticular in shape; it thins out and disappears entirely from the section, and has no lateral equivalent. The sandstone lettered *b* is shown to grade over into a shale which is its lateral equivalent. Sandstone *a* apparently is the result of sedimentation under such conditions that sand only was deposited. Sandstone *b* apparently represents the results of sedimentation under such conditions that sands and muds were being laid down at the same time, according to the local variation in the strength of currents which assorted the material, resulting in a gradual gradation from one into the other. As regards these two classes of sandstones, observations have shown that the lens-like beds are apt to be more persistent and to extend for longer distances, while the sandstones which grade into shales vary from place to place in an exceedingly irregular way.

Drilling operations have shown that in many places in the Kansas fields we have sandstone beds occurring under irregular conditions which may be explained satisfactorily by giving proper attention to the hypothetical cases above outlined. It is not at all unusual to find a good, productive sandstone in one place and no sandstone at all near by. The Cherokee shales, for example, usually are moderately well filled with sandstone of irregular thickness and lateral extent. But some wells

have been drilled entirely through these shales without encountering any sandstone at all. This was notably so in a well drilled a short distance east of Moran, where the drill passed entirely through the Cherokee shales and into the top of the Mississippian limestone without meeting any sandstone whatever, although only a few miles to the west lies the wonderful Iola gas-field, which obtains all its gas from thick, heavy sandstone beds.

Quite as likely one will find a sandrock thickening to an unusual thickness. This latter condition is well illustrated in the strong gas-field lying to the north of Cherryvale and east of Neodesha, in the southeast corner of Wilson county. Some of the wells here found the sandstone approximately 100 feet in thickness, with correspondingly large volumes of gas, but less than five miles in any direction the sand was no more than the ordinary.

In order to give a few detailed examples of comparatively rapid sand variations, two areas are chosen, one a few miles southeast of Humboldt, where the Oread Oil Company and the Kansas Crude Oil Company, later changed to the Reynolds Oil Company, did some drilling.

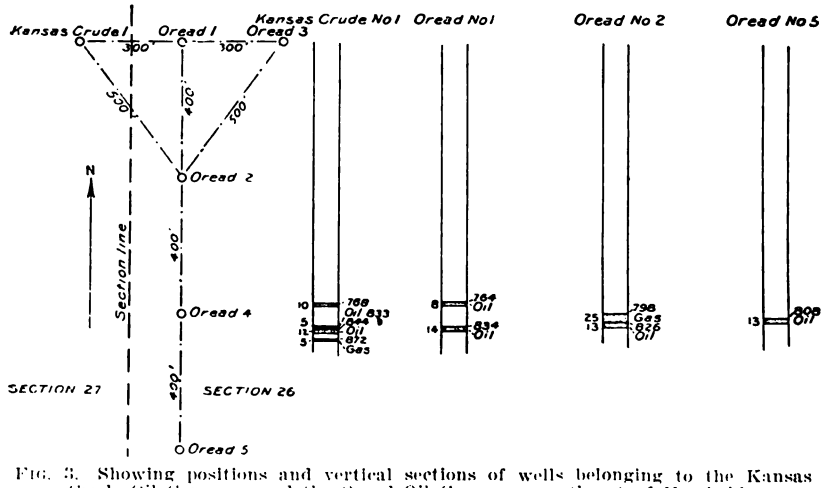

FIG. 3. Showing positions and vertical sections of wells belonging to the Kansas Crude Oil Company and the Oread Oil Company, southeast of Humboldt.

In figure 3 the relative positions of certain wells are shown in the left-hand part and a portion of the record of each is shown drawn to scale in the right-hand part of the figure. The wells are in sections 26 and 27, township 26 south, range 18 east, about four miles southeast of Humboldt. The surface for

the area described is almost level. The wells in section 26 belong to the Oread Oil and Gas Company and those in section 27 to the Kansas Crude Oil Company. The well called Kansas Crude No. 1 was drilled to a total depth of 880 feet. At 768 feet 10 feet of sand was found, which was practically barren of oil. At 833 feet 5 feet of sand was found which was rich in oil, and at 844 feet 12 feet of sand was encountered that was productive. The base of this sand was at 856 feet. Below this point 16 feet of shale was passed through, then 5 feet of sand, which produced close to one million feet of gas per day. The drill went 3 feet farther in light-gray shale and was then stopped.

Oread well No. 1 is situated 300 feet due east of the well just described. In it 8 feet of sand rich in oil was encountered at 764 feet, corresponding fairly well with the 10 feet of sand in the Kansas Crude well. Below it 62 feet of shale was passed through and then 14 feet of productive oil-sand, corresponding very well with the 12-foot bed of sand in the first well described. After passing 9 feet in shale the drill was stopped, as it was not desired to reach the gas which, according to the record of the Kansas Crude well, might be expected below.

Oread well No. 2 was located 400 feet south of Oread No. 1. At a depth of 798 feet 25 feet of sand was found, which produced a large quantity of gas. Below this 4 feet of black shale, partly saturated with oil, was passed through, and then 13 feet of productive oil-sand, the bottom of which was 839 feet below the surface. It will be noted that in this well no sandstone was found at a depth of 770 feet where, according to the records of the other wells, it might have been expected, while a bed of gas-bearing sand 25 feet thick was encountered at 798 feet, no trace of which was found in either of the other two wells.

The next well drilled was Oread No. 3. In it no oil was found, but a strong flow of gas was obtained from a sand at a depth of about 800 feet, doubtless corresponding to the gas-sand found in well No. 2.

Well No. 4 was located 400 feet south of No. 2. In it a productive oil-sand was reached at 835 feet, corresponding to the oil-sand in the other three wells

Well No. 5 was located 400 feet south of well No. 4. At 800 feet a small flow of gas was obtained, and at 808 feet 13 feet

of productive oil-sand was encountered, corresponding with the oil-sands in the other wells.

Reviewing what has been stated concerning these six wells it is seen that there is a sandstone 10 feet in thickness in Kansas Crude No. 1, which disappears entirely in a distance of less than 600 feet to the east, and less than 500 feet to the southeast, as it is totally wanting in Oread Nos. 2 and 3. The 25-foot gas-sand in Oread No. 2 is not represented in Oread No. 1 or in the Kansas Crude No. 1. This illustrates the rapid transition in the character of the strata.

In regard to the gas horizons it will be noted that a strong flow of gas was obtained from a sand lying beneath an oil-sand in Kansas Crude No. 1, and that the stronger flow of gas was obtained from a sand above the oil-sand in Oread No. 2, only 500 feet away. It is impossible to say what would have developed in Oread No. 3 had the drill gone deeper, but the main oil-sand might have been reached. Likewise, it is impossible to determine whether the Oread wells, if they had been drilled deeper, would have reached the gas at 875 feet, the depth at which it was encountered at Kansas Crude No. 1.

The records of wells in sections 32 and 33 in township 26 south, range 18 east, in the valley of Neosho river between Humboldt and Chanute, furnish further illustrations of the variation in the horizon and lateral extent of the oil- and gas-sands. In the southeast quarter of section 33, a number of good oil-wells were found, with a gas-well but a few hundred feet away.

In the Neosho river valley, east of Chanute, oil-sands generally, but not always, lie above the gas-sands. In most wells the oil-sand is reached at from 700 to 750 feet. Usually there is a bed of shale about 40 feet thick below the oil-sand, and beneath this a heavy bed of sand carrying large quantities of gas. The first gas-wells at Chanute went through the oil-sands, and it was their showing of oil that induced Mr. Knapp to begin drilling for oil in the Chanute field. The gas-wells there had an initial capacity of from one to four million cubic feet per day, and others recently drilled a mile or more to the east across the river had an even greater initial flow. From the sandstone only 40 feet above this large volume of gas oil was produced having so little gas with it that the pressure was not sufficient to cause the wells to flow, thus showing conclusively that there is no communication between the two sands.

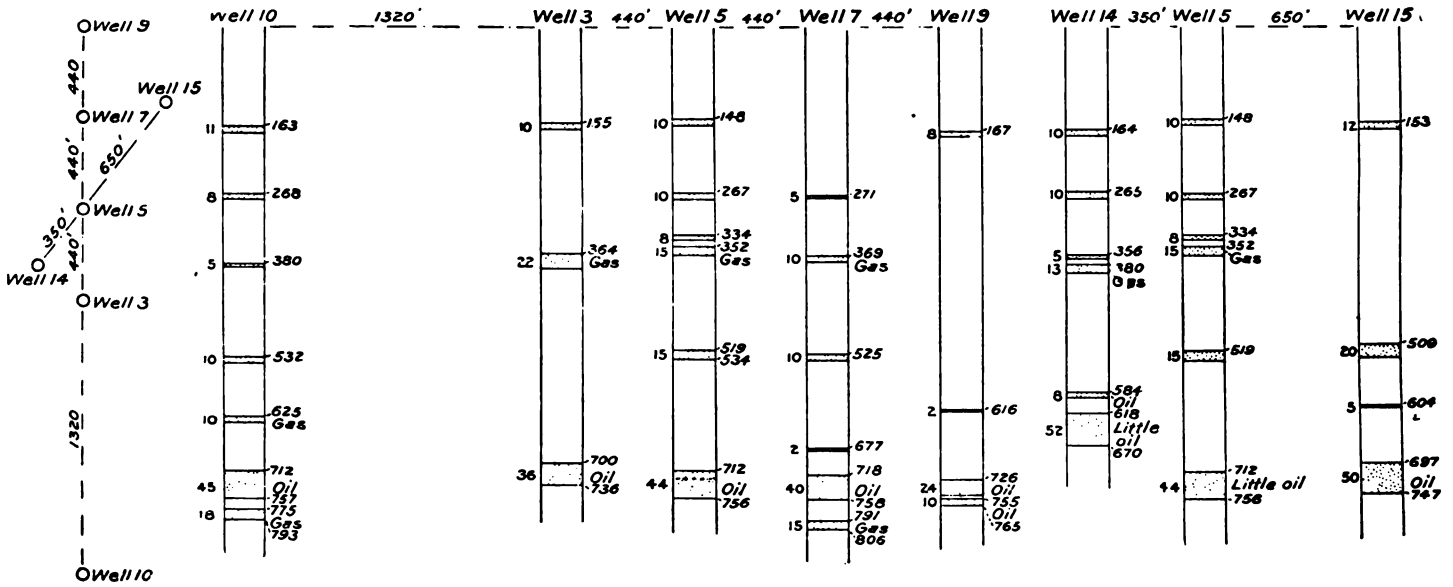

FIG. 4. Showing relative positions and partial logs of wells just east of Chanute, in the Neosho river valley.

Along the east side of the west half of the southwest quarter of section 22, township 27 south, range 18 east, in the river valley just east of Chanute, Mr. Knapp drilled five wells on a north-south line. The records of these wells were carefully kept, as were the records of two wells one on either side of this line. The lower portions of the logs of these wells, showing the sandstones encountered, are presented, drawn to a scale, in figure 4. The relative distance between the wells is indicated on the diagram and in the arrangement of the well sections. The surface is almost level, as the wells are in Neosho valley, where the slope is not more than 2 or 3 feet to the mile. A glance at figure 4 will shown the irregularity in the horizons at which the sands were encountered. In some cases the records of adjacent wells correspond closely in regard to particular sands, but it will be noted that some of the sands which are well marked in certain wells are wholly absent in others.

It is useless to pad this report with further detailed illustrations. Those just given from the vicinity of Humboldt and Chanute are exact reports from actual measurements. No pool of any considerable importance has been discovered anywhere in the entire Midcontinental field which does not yield similar illustrations of the irregularity of both vertical and horizontal extent of the sandstone beds. Probably one of the longest stretches of unbroken sandstone lies principally in Oklahoma in the vicinity of Bartlesville, with the north extremity reaching into Kansas. Here, so far as now known, a stretch of many miles has been found without any important break in the sandstone. And yet an occasional dry well or dry area is found, which probably is due to similar changes of the sandrock.

In order to understand these apparent variations of sandrock conditions, it might be helpful to study modern ocean beaches. As is well known, along our ocean beaches in places we find an unbroken beach of pure sand many miles in extent. In other places the beach is cut up in a great variety of ways by streams crossing it to enter the ocean, by mud-banks, by gravel-bars and other familiar variations. Should we make a vertical section of such a beach parallel with the coast under the first-named conditions, it would appear almost uniform for a long distance, while under the second set of conditions it would be very much more irregular. If, now, a transverse

section be made in a similar manner along the ocean beaches in general, it will be found the character of the sand changes more frequently in a given distance. In other words, it is possible to find long stretches of sandy beach with practically uniform characters parallel to the coastal line, although the mere fact of parallelism does not guarantee uniformity of conditions, while in transverse directions almost invariably we find quite a variation of conditions.

The lesson is easily learned. A long stretch of uniform conditions, such as along the line between the Osage and Cherokee nations, or along the Neosho river valley from Chanute to Humboldt, or many other places that might be named in almost any oil-field in America, doubtless corresponds to a modern ocean beach as described; while areas filled with rapid variations, dry wells and good wells mixed together apparently indiscriminately, doubtless correspond to the other character of coastal beaches. In the matter of direction, also, the similarity is great. Our Atlantic coast in general trends northeast and southwest, but how easy it is to find local trends in many other directions. Likewise, the Appalachian oil-fields and Midcontinental oil-fields in general trend northeast and southwest, but in each of them locally we have many variations from such.

Relation of Geologic Structure to Oil and Gas Pools.

ANTICLINAL ARCHES AND SYNCLINAL TROUGHS.

In many oil-fields and gas-fields there seems to be a certain definite relation between local geologic structure and the pools in which oil and gas are found. This idea was first worked out for the Appalachian region. Briefly stated, it is that gas-pools and oil-pools are found under anticlinal arches and along the branches or limbs of such arches, while water-pools should be expected under the synclinal troughs. Nature in her modifications of the horizontal bedding-plains of stratified rocks often has thrown them into undulating positions of crests and troughs. Through the influence of certain dynamic processes, rock strata have been lifted here and depressed there, producing an arch-like dome in one place and a corresponding trough in another. If, now, a productive sandstone should happen to occur in such a place far beneath the surface with an overlying oil-tight and gas-tight shale-bed, the tendency would be for the three materials—water, oil and gas—to arrange

themselves in the order of their specific gravity. This would put the gas at the top of an arch, with oil next below and water still farther down. If, now, the supply of gas is sufficiently large it may occupy the entire arch extending away down the sides or limbs of the anticline. If, however, the supply of gas should be small, with oil in comparative abundance, the gas would be at the top of the arch, oil next below, and water still below the oil.

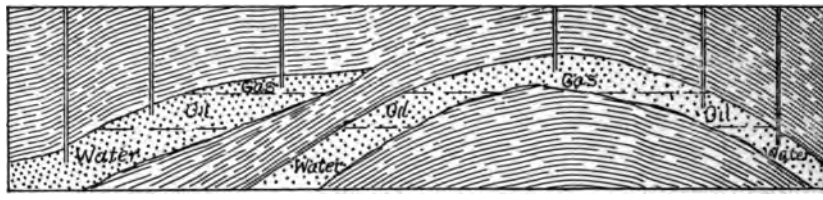

FIG. 5. Showing how gas, oil and water may be in the same sand and how each may be tapped by a well.

Figure 5 will serve as a diagram illustrating how such conditions can be brought about and how wells put down in the several different places, as shown, may encounter several different conditions. In each case it will be understood that should oil be absent gas will lie immediately above the water. Should a well strike gas under these conditions with oil below the gas, after the latter is exhausted oil will enter the well, and may become very profitable. The last stages of either oil-well or gas-well probably will be that of a well filled with water.

If nature by acting upon a bed of sandstone originally horizontal in position should throw it into the form of a gentle arch, the axis of the arch trending parallel with a mountain range, such an anticlinal arch may become exceedingly productive of either oil or gas, but particularly the latter. It sometimes happens that the direction of one of these arches practically coincides with the direction of an old ocean beach along which pure, clean sand was gathered, producing a porous sandstone capable of holding large quantities of oil or gas. Such a condition produces the best known wells—those of the tremendous capacity of the Appalachian region. Large mountain ranges are not an essential for this condition, because we may have gentle swells in level countries where all the essential conditions are produced as above explained. Such is the case in the great eastern Indiana gas-fields. Here a gentle swell or arch in the Trenton limestone has been one of the main factors

in determining the location of that unusually rich field. The inclination of the rock bedding-plains need not be more than from 5 to 10 feet to the mile, although they may be as great as 20 or 30, or even 100 or 200 feet to the mile. The steeper the inclination, naturally the narrower the productive area is likely to be, because with a rapid dip of the formations the productive sandstone soon would be carried so far beneath the surface that water is almost sure to be present. A study of the simple illustration, figure 5, will show one how we may have a series of wells close together, one a good gas-well, one an oil-well, and the other one filled with water. The proper way to consider this question is that all porous rocks are filled with water, with an occasional exception of a bubble of gas or oil being found in the water. This bubble may be small or large, even to many miles in horizontal extent. All too frequently, however, such a bubble is narrow and soon exhausted. So long as rains continue to fall on the surface and the water works its way downward, that long there will be a tendency for water to drive out all fluids of lighter gravity, and therefore the water pressure will tend to drive both oil and gas upward and outward. The same agencies cause the water to follow the gas and oil as they become exhausted.

It is easy to imagine certain variations from those given in figure 5, so that we may have a body of oil or gas in a sandrock connected directly with a body of water at one side, the water shutting out the oil or gas from the drill-hole. Exhausting the water by pumping in such cases would allow the oil gradually to approach the well and ultimately develop into a reasonably good oil-well. This condition has been found in many places in different oils and likely will be found many times in the future. It is due to a certain combination of oil and water conditions with the well accidentally being drilled so as to hit the water near the oil bubble.

If the reader will recall what has been said about the irregularity of sandstone production on our present ocean beaches and will understand that all masses of sandrock, whether or not they are producers of oil and gas, were formed along old ocean beaches in the same manner, he will be able to understand some of the perplexing conditions found in many oil-fields.

All anticlinal arches have been formed subsequent to the formation of the sand-beds. It is a mere accident, therefore,

to find such an arch with its axis of direction paralleling the sand-beds. Quite as often they cut them transversely and at various angles. Here, again, we may learn a lesson from the Appalachian fields. It is well established by geologists that, at the time the productive sand-beds were accumulating, a long, slender arm of the ocean occupied the position now held by the Appalachian mountains, an ocean arm forming an inland sea very similar in character to the Red Sea, or to the Gulf of California. Naturally, therefore, the sand-beds or sand-beaches were long and slender, paralleling the arm of the ocean. Later, when the mountains were elevated, folds and flexures were produced which, by strange coincidence, almost exactly paralleled the ancient coast line of this inland ocean. If, therefore, a geological section is drawn parallel to the mountain ranges, it shows but little variation and the given sandrock is approximately at a constant depth beneath the surface. If such a section is drawn transverse to the mountain range, however, then the anticlinal arches and the synclinal troughs become apparent. It is along these great anticlinal regions that the wonderful gas-wells of West Virginia and Pennsylvania are found.

STRUCTURE IN THE MIDCONTINENTAL OIL-FIELDS.

Out in the Midcontinental field we have a set of conditions slightly different from those of other fields, although, after all, they are strongly similar. From good geological evidence it may be stated that the old ocean beach had a trend approximately north and south, bearing a little to the northeast and southwest through the eastern part of Kansas and gradually veering eastward in Oklahoma south of Tulsa. The dip here in Kansas is due to influences which produced the Ozark hills in southwest Missouri. In the vicinity of Kansas City, Ottawa, Paola, Garnett, etc., the rocks dip gently to the northwest. Along the southern line of Kansas the maximum dip is approximately west, possibly veering a little southwest. Farther south, in Oklahoma, the southwestern dip becomes more apparent. The same formations swing around to the east in the vicinity of Fort Smith, where a new set of earth movements have produced effects and the dip of the rock is more often in a north and south direction.

In general, we may look for gentle anticlinal arches trending northeast and southwest in Kansas. They are so mild that they can scarcely be found. In fact, erosion has done its work so well that in many cases the eastern sides of such anticlinal

arches have been worn away, leaving the west limbs only. South of the state line the anticlinal regions probably become a little more noticeable and doubtless have a little greater influence. Such a one evidently passes Bartlesville and coincides with the line of gas-wells east of Bartlesville. Probably, also, there is a wave-crest west of this closely paralleling the boundary between Cherokee and Osage Indian lands. In Kansas we have such gentle waves both east and west of Chanute reaching for miles in nearly a north and south direction, and the wonderful gas-wells a few miles west of Chanute are along the summit of such an anticlinal ridge, while the oil-wells and gas-wells lying east likewise are along the summit of a very mild anticline.

In a number of places in the state anticlinal arches with gentle dips have been found with directions differing from those named. North of Fort Scott a short distance such an one exists, and for more than ten years the writer has tried to prevail upon prospectors to drill wells along its summit, but thus far without success. Farther west, at Elmdale, and probably reaching all the way from Elmdale to Arkansas City, an anticlinal ridge exists which is moderately productive at Elmdale, Augusta and Arkansas City. The discovery of gas at the latter place, so far as known to the writer, was accidental. At Elmdale, however, a member of the State Geological Survey, Dr. J. W. Beede, pointed out the anticlinal ridge to some of the business men of that place, with the result of a nice gas-pool being uncovered.

Emphasis, therefore, should be placed upon the statement that anticlines of themselves do not produce gas or oil. Probably we have thousands of unproductive anticlines in America for every one that is productive. A mere anticline of itself is of but little importance. First, there must be a proper accumulation of sand or other material to produce a porous rock into which oil and gas may be forced after being manufactured in nature's laboratory. Next, the oil and gas must have been made and forced into such a porous rock; and lastly, the anticline made must have coincided with these other two conditions. If one is in an area known to be liable to contain oil and gas beneath the surface, the prospector should seek out anticlinal ridges, which may be detected by the position of the stratified rock at the surface. If he is fortunate enough to find such a structure, he should prosecute his prospecting along such

lines rather than elsewhere. If nature in her beneficence has filled the ground with these materials, prospecting along the anticlinal ridges most likely will discover them.

The most marked structural features of eastern Kansas in connection with results of surface erosion are long, slender dip-plains extending northeast and southwest across the state. Two of these particularly are well marked. In the vicinity of Uniontown the Bethany Falls limestone, in connection with others overlying it, forms a prominent escarpment miles in length. According to altitudes marked on the United States Geological Survey topographic sheet of the Iola quadrangle, the top of these limestones twenty-three miles east of Chanute has an elevation of 1100 feet. They dip gently to the west and pass under the Chanute shales five or six miles east of Chanute and are reached by wells in the Neosho river valley at Chanute. Their dip throughout this distance is between 300 and 400 feet. Erosion has done its work variably at different places on the upper surface of the limestones, in some places having removed the Chanute shales entirely and at other places left them from 10 to 75 feet thick. This dip-plain, with a relatively thin shale and soil covering, reaches many miles northeast and southwest. The eastern limit of it possibly represents the summit of an anticline from which the eastern limb has been removed entirely by erosion. It is difficult to decide definitely what the actual conditions are.

The next most prominent dip-plain in the state is that on top of the Stanton limestone. In some places the Stanton and Allen limestones coalesce and elsewhere they usually are so close together they form but one escarpment, while throughout a short distance only is the intervening shale-bed thick enough to give them especially different outcropping lines, all of which is plainly shown in figures 1 and 2 of plate XII. Their eastern outcropping line practically parallels the outcropping line of the Bethany Falls limestone. Overlying the Stanton is an aggregate of about 300 feet of shales with only a small limestone interbedded—the Kickapoo limestone—which seldom has produced any particular influence on surface features. The Oread limestone, on top of the Lawrence shales, therefore, limits the next escarpment to the west. This gives us a long, narrow zone northeast and southwest, with the Stanton limestone at its base and the overlying shales somewhat irregularly but

almost entirely removed westward to the outcroppings of the Oread limestone.

The Stanton limestone underlies the town of Olathe, from which the surface dips gently to the west as far as Lawrence, a distance of nearly twenty-five miles. Likewise, the same limestone has its eastern outcropping near Kincaid. On the west a stream between Kincaid and Colony cuts through it, but neglecting this we have the dip-plain reaching west from Kincaid to the bluffs west of Le Roy, a distance of twenty-eight miles. Again the Stanton limestone lies on top of the escarpment six miles west of Chanute and forms a dip-plain from which the overlying shales have been almost entirely removed westward to the vicinity of Toronto. The outlying hills southeast of Toronto are capped by the Oread limestone, the first important limestone above the Stanton, which gives a dip-plain for the Stanton limestone here of about eighteen miles. The same dip-plain is prominent west of Neodesha, beginning with bluffs west of Fall river and extending westward to Longton, a distance of twenty-three or twenty-four miles. In this part of the state, however, the Chautauqua sandstones occupy the principal thickness of the Lawrence shales. By their varying power of resisting erosion a very hilly country is produced throughout the western part of the dip-plain, making the range of hills extend some miles east of the Oread limestone outcroppings. However, the dip-plain extends westward in a typical manner more than half of the distance named.

It is moderately certain that, in some places, at least, the summits of the prominent escarpments are the summits of anticlinal ridges. The Stanton escarpment near Chanute is a good example. Here the underlying shales and limestones dip gently to the east, which tells the story. It is an interesting fact that the large gas-field developed west of Chanute is on the summit of this anticlinal arch.

Probably almost no phase of the detailed geology of the Midcontinental field is of more practical importance than the one now under discussion. It must be said that in general our Kansas fields contain only very mild structural features. This, in connection with the work of surface erosion, renders it difficult to establish the presence or absence of anticlinal arches. The great gas-field at Iola is on the dip-plain of the Iola limestone, which has an outcropping near Moran at an elevation of 1100 feet. According to the topographic map,

Iola quadrangle, the dip-plain is practically uniform to Iola, where the elevation of the upper surface of the limestone is about 90 feet, making a dip of 140 feet in twelve miles. Throughout this distance the overlying shale-bed is almost entirely removed, but not with sufficient completeness to expose the limestone all of the way. It is difficult to believe that there is any form of an anticlinal arch here trending northeast and southwest.

Five miles to the north of Iola is the little town of Carlyle, situated on Deer creek, a stream flowing southwest. This creek certainly lies in a synclinal trough. On the northwest side the rocks rise to the north and northwest, while on the east they rise likewise. In fact, here is one of the highest angles of dip known in the state, where the Allen limestone rises from the bed of Deer creek southeastward. This syncline seems to follow down Deer creek to the Neosho river and down the Neosho river to below Chanute. In this way, therefore, there is a rising of the rocks both eastward and westward from the Neosho river and Deer creek troughs. The strong gas-wells of Iola, it is true, lie east of this synclinal trough. But as the rocks continue to rise eastward to Moran one would expect to find strong gas extending that far, with a better supply of it in the vicinity of Moran than at any intermediate point, provided an upward-sloping inclination of bedding-plains would produce it.

Here, therefore, we must conclude that structural conditions have but little, if anything, to do with the great Iola gas-field, and must look for the explanation of its existence to some other particular geologic conditions. It would seem that the explanation is found, in part at least, in the character of the sandrock 900 feet below the surface rather than in any structural conditions which may have existed.

No small amount of labor has been expended in investigating this subject. A study of the seven county maps herein included will reveal the fact that our oil-fields and gas-fields are scattered here and there with apparent irregularity throughout the territory. We have been unable thus far to connect them with structural conditions to a sufficient extent to justify the general conclusion that structural conditions alone control the presence of oil or gas. The comparatively rich oil-wells in the Neosho river valley just mentioned certainly are in a synclinal trough; and, likewise, the gas-wells in the

same valley, which draw their supply from a sandstone beneath the oil-producing sandstone, as already explained, certainly are in a synclinal trough. These first gas-wells at Chanute practically gave Chanute its prominence as an oil and gas center, in spite of the fact that they draw their supply from a structural valley. We must conclude, consequently, that, no matter how important structural relations may be elsewhere, they are of only moderate importance in Kansas.

CHAPTER V.

LIFE OF OIL-WELLS AND GAS-WELLS.—GAS PRESSURE. —ORIGIN OF OIL AND GAS.

By Erasmus Haworth.

SECOND in importance only to the discovery of oil and gas is the question of the durability of the same. How long will a well produce oil? How long will a well produce gas? Our experience in the Midcontinental field does not permit such questions to be answered fully, because in most cases our wells are so young they have not become exhausted. Our oil-wells show more signs of exhaustion than our gas-wells do. In some instances, where wells have been pumped continuously for years, they are practically exhausted. The most remarkable case of this kind, doubtless, was in the little town of Peru. Here wells were put down on almost every town lot, each of which drew its supply of oil from the same sandstone, about 1000 feet below the surface. For a period of six months lotowners apparently vied with each other in an endeavor to get the oil exhausted first, and in so doing drilled at least a score of wells where but one should have been drilled. Under such circumstances no one could be surprised to find that in less than eighteen months' time the supply of oil was practically exhausted and pumps, well-casings, etc., went into the junk-pile.

The other extremity is found at Neodesha. Here Guffey & Gailey drilled wells in 1894, some of which are still productive, fourteen years later. The oil-wells drilled in the Neosho river valley in the vicinity of Humboldt and Chanute in 1901, 1902 and 1903, in a great measure have been abandoned. This was brought about from a number of causes, the principal one of which was that the supply of oil decreased greatly. Next to this should be mentioned the great decline in prices. Throughout the period of most active development Neosho river valley oil was selling at from 85 cents to $1.20. The highest price reached at any time in the Midcontinental field was in

the spring of 1903, when oil in Chautauqua county sold at $1.38 a barrel. This period of high prices lasted but a short time until the price was cut to as low as 40 cents, and throughout the greater part of 1906 and 1907 and thus far in 1908 it has been from 41 cents to 42 cents for the best oil in the entire territory.

A third reason of considerable importance for the great falling off in production was the comparatively heavy oil produced in many places about Chanute and Humboldt. Some of this oil graded from 30° B. to above 32° B. During the latter part of the year 1903 the Prairie Oil Company, for the purpose of grading oils, drew an east and west line through the middle of Wilson and Neosho counties, and classed all oils north of this as heavy oils and those south as light, with a corresponding difference in price. This was a hard blow to the Neosho river valley oils, and of course had a tendency to curtail development and production. Later they began buying strictly on a gravity basis, and have continued on this basis to the present time. They grade all oils with a gravity of 32° B. and upward in one class and pay a certain price. For oils heavier they deduct a certain amount for each half degree or fraction thereof. This discrimination so discouraged producers whose wells produced heavy oil that it was one of the principal causes for the development work and production to decline so rapidly.

It was in July, 1903, that the first oil was found near Bolton, southwest of Independence. A number of remarkable wells were soon produced, some of which flowed at the rate of 1000 barrels per day. The history of this development has already been given in the interesting letter written by Hon. G. L. Banks, of Independence. These strong wells retained their flow only a few weeks and declined quite rapidly to pumping propositions. At the present time no wells in Montgomery county are producing very much, the decline being due in part to heavy oil predominating, in part to the decrease in price, and in part to the supply of oil being so nearly exhausted.

The longevity of gas-wells seems to be quite different from that of oil-wells. In general, the life of a gas-well is much greater. Here, however, we find considerable variation. The first large gas-field to be developed was at Iola. The history of this field, as already given, was that the first large wells

were found in 1894 and 1895. The first zinc smelter was established there in 1897 and the first Portland cement plant in 1899. The zinc smelters and Portland cement plants use an enormous amount of gas. These, in connection with the brick-kilns and the domestic consumption, draw very heavily on the gas supply. At the present time, June, 1908, it is well known that the original Iola gas-pool is very largely exhausted. And yet the tenacity with which the supply holds out is both surprising and gratifying to every one. For about twelve years a strong field has been drawn upon with unusual rapidity, and still is able to give a moderate account of itself.

The gas-fields in the vicinity of Coffeyville probably are even more remarkable. The first wells found here were under the city itself in 1892, 1893 and 1894. It is true that these have been exhausted for years, but the field to the west of Coffeyville has been drawn upon much more extensively and has withstood the drain surprisingly well. Coffeyville to-day is better supplied with gas than ever before, although for fifteen years it has been piped in her streets. During the last ten years particularly the drain has been very heavy, for Coffeyville has large manufacturing interests, particularly glass plants, which are great consumers of gas. The Coffeyville gas-field and the Independence gas-field practically coalesce. The Independence field lies to the south of Independence and Bolton, while the best gas-fields at Coffeyville lie to the west and extend out to Deering and beyond. This particular area practically coalesces with the great Caney gas-field in southwest Montgomery county, which in turn seems to be almost continuous with the gas-field of the Cherokee Nation, from Caney southward by way of Dewey and Bartlesville to Tulsa and beyond. Individual wells grow weak and occasionally, but not often, are abandoned, while the territory as a whole seems to be as good or better than ever before.

The question is asked frequently as to how long gas-wells will last. It must be said that our experience in Kansas is too short to answer such a question intelligently. Should the larger question as to the durability of the Kansas fields be raised, the answer would be more positive in one respect, now that, with the probabilities of new developments in the future as in the past, there seems to be little danger of the supply becoming exhausted within the next ten or twenty years. Beyond this probably no one would be safe in predicting. From

the standpoint of geology, it must be said that there are good reasons for expecting great gas-fields will be developed in the future, as in the past. Only a small fraction of our territory has yet been prospected. No one can bring forward any reasons for considering the fields already developed more fortunately located than other areas not yet tested.

On Pressure in Gas-wells.

Why does gas exert such a pressure in gas-wells? Why does the pressure in gas-wells decline with use? These two questions are asked frequently, and occasionally attempts are made to answer them. If we could know the origin of gas, how nature manufactured it, and how it is transported to its present hiding-places, possibly we could answer the questions just asked. In the early days of gas-wells in the Appalachian region it was assumed that in some way the rocks yielded as though made of compressible materials and that by so yielding the pressure in some way was set up and, hence, the term "rock pressure" became incorporated into our language and still remains in common use with the great majority of oil and gas men. Some geologists were led to believe the same and, in a few instances, even defended the proposition. More recently, however, it has been concluded by geologists generally that the rock masses do not yield to pressure; at least do not in the way previously considered, and that therefore the term "rock pressure" is a misnomer.

The next general opinion expressed was that gas pressure is caused by water pressure, the assumption being that rain-water constantly falling upon the surface of the earth is as constantly penetrating into the earth and tending to drive out from rock voids oil and gas and whatever else may be present lighter than water. Under this conclusion pressure on gas in wells ordinarily should be proportional to their depths. The late Professor Orton, in studying certain wells in southwestern New York, found that the pressure exerted by the gas was greater than could be caused by a column of water with a height equal to the depth of the well. Consequently, he abandoned this idea and gave us nothing in return. Dr. I. C. White, in his estimable report on oil and gas for West Virginia, refers to this and concludes the explanation should be that nature has manufactured so much gas in a given place, and that the pressure is dependent upon the amount of gas manufactured in

proportion to the space available for holding it. If I understand his paper clearly, it is comparable to gas being made in the old-fashioned gas-generator which could not change its volume no matter how much gas was manufactured within it.

It seems to the writer that there must be certain conditions existing that have not yet been touched upon by geologists, and which must be understood before the cause of gas pressure can be thoroughly explained. A few of the difficulties encountered, should either view named above be accepted, may here be recalled.

Throughout the Midcontinental field, almost without exception, the gas pressure is proportional to depth in wells. This of itself is strongly favorable to the older idea of water pressure being the governing cause. Considerable pains have been taken to learn the initial pressure and the corresponding depth of wells throughout the entire area. There is not a perfect agreement between depth and pressure, but it is nearly so. Reckoning water pressure at forty-three pounds per hundred feet, for easy calculation, and allowing a variable depth of from 25 to 100 feet from the surface before reaching the permanent ground-water level, there is scarcely a well in the entire region that does not correspond fairly well with the pressure exerted by a column of water for the given depth. A difficulty in this line, however, is met by many wells which do not exactly conform to this condition. In one instance, of somewhat doubtful authenticity, a well was reported over 1000 feet deep with a pressure of less than 250 pounds, while a well half a mile away was reported by the same authority as having a pressure of about 375 pounds at 900 feet deep. This is the only instance thus far noted where it was claimed that the deeper well had the lighter pressure, and therefore its authenticity is considered doubtful. But we have many cases of a variation from well to well of from ten to twenty-five or fifty pounds, which should not be expected if the pressure were entirely due to water pressure. It should be remembered, however, that there may be certain underground conditions that would interfere in the way with normal water pressure, and that such conditions would account for such variations. Might it not be true that the wells in southwestern New York and elsewhere where the water pressure is less than gas pressure that the latter may be increased by water having an artesian effect? If gas is given a pressure by ground-water and the ground-

water in one case would rise only to within 200 feet of the surface and in another case would rise 100 feet above the surface, then the same water pressures might be sufficient cause for a difference in gas pressure.

Another difficulty of understanding gas pressure is the manner of decline in a gas-well when used. It seems to be universally true that as the gas becomes exhausted in a well from use the pressure declines gradually. Why should this be so? If the pressure in any way is due to water pressure, why should it decline gradually by use? For example, suppose we have an ordinary gas-receiver instead of the sandrock, and suppose that a pipe 1000 feet high connected with this is filled with water; it would then give a gas pressure in the receiver of about 430 pounds. Should the valve be opened and the gas allowed to escape water would gradually take its place, and the only decrease in pressure would be the decrease in height of the water column. If we change the gas-receiver in our problem to a gas-sand 20 feet thick with the bottom 1000 feet underground, then the pressure should decline only the amount produced by a column of water 20 feet high, or about eight pounds. And so long as any gas can be obtained at all we should have a pressure equal to the initial pressure minus this small amount.

But no natural-gas wells decline in this manner. A well with an initial pressure of 500 pounds in the course of time will drop to 400, then to 300, then to 100, then to 50, and to still smaller fractions if it is used longer. Should gas pressure be due to the gas being manufactured in the ground until a certain pressure is established then we would expect it to decline just as observation shows that it does. If this is the right explanation, however, for its origin, why is it that the pressure so generally the world over corresponds closely with the depth?

It would seem to the writer that possibly a satisfactory solution may be had by agreeing first with Leslie and White that the gas has been generated near where found, and the pressure primarily was due to the amount generated in proportion to the size of the receptacle into which it was forced. As the ground is so filled with water, this water in places might act as a water valve. If, now, the pressure should become sufficiently great, it would leap through the water valve and the gas left behind would exist under a pressure practically determined by a column of water, although possibly many times

as much gas has escaped as would be found in the ground by drilling. If now we find a porous stratum which is gas-bearing overlaid by an impervious bed of rock, such as fine-grained shale, quite possibly the ground-water in such a sandstone will exist under artesian conditions and may exert a pressure considerably more than would be exerted by a column of water equal in height to the depth of the well. This, of course, would be determined should a well be drilled into a water-pocket. But if the wells drilled hit gas-pools, the gas would be found to exist under a pressure greater than the depth of the well would imply.

Coming now to the matter of exhaustion of gas-wells, it seems that it may be possible, as suggested to the writer in conversation by Dr. George I. Adams, that the real explanation here of the gradual decrease of pressure may be due to the slow movement of water within the sandrock. Suppose we have a well drilled into a gas bubble in the sandrock, which bubble is entirely surrounded by water on all its borders. Should the well be used lavishly gas would travel from different places in the pool to the foot of the well and escape more rapidly than the water could close in on the ever-decreasing bubble of gas, and in this way the gas pressure would be decreased gradually as the well became exhausted. If, however, the well should be closed for a period of weeks or months, according to this explanation we would expect it to regain its pressure and ultimately reach the normal pressure when the well was first drilled. Observations in the Kansas gas-field in a measure, although not with entire satisfaction, accord with this explanation. It has been noted over and over again in the Iola field and in many others that a gas-well which has been used rapidly for some months will have its pressure run down, and will recuperate or regain the pressure by a period of idleness. It may be said, in fact, that this is the rule with Kansas gas-wells. However, it is observed in some instances that wells may be completely exhausted and casing drawn without their ever becoming rejuvenated by idleness. One of the best illustrations of this kind is a well near the little town of Benedict. In 1895 Guffey & Gailey drilled a well here in the hope of finding oil. Instead, they found a very strong gas-well. After a period of idleness a pipe-line was laid to Chanute, and for more than two years this one well supplied the entire city of Chanute. In the course of time its pressure

gradually declined, and finally, after the well became entirely exhausted, the pipe-line was taken up, the casing drawn, and the well destroyed. On the supposition of the slow travel of water being the real reason for the gradual decline of gas-wells it is difficult to understand such a phenomenon as here mentioned.

Origin of Oil and Gas.

During recent times much has been written regarding the origin of oil and gas, personal debates of greater or less magnitude have been engaged in, various articles in magazines and state reports have been published on the subject, and yet it would seem that we are little, if any, closer a final solution of the question than we were forty years ago.

In a general way the views held by scientists may be grouped into two classes, the so-called chemical theory and the organic theory, each of which will be outlined here and a few arguments in favor of each presented, in order that the reader may have the subject properly before him. So long as there is a difference of opinion on the subject, just that long care should be taken not to become dogmatic. The writer has only one object in this discussion, and that is to place before his readers in a measure a correct outline of the present condition of thought on this great and important question. It matters not what his views are, *per se*, nor the views of any other one or half dozen individuals, only so far as these individual views may be based upon actual observations. It should be remembered that here is a great question in a measure yet unanswered, although quite probably not unanswerable. Scientists generally believe that could we determine the origin of oil and gas it might be turned to great practical value in locating pools of these valuable hydrocarbons.

CHEMICAL THEORY.

In a general way the chemical theory may be stated to be a belief that in some manner water acting upon hot metals is decomposed, the oxygen being absorbed by the metals and the hydrogen thus set free uniting with carbon and forming a large number of hydrocarbons, namely, petroleum and natural gas. There seems to be a considerable variety of details regarding such beliefs, and yet these variations are of minor importance.

In 1866 the distinguished French chemist Bertholet ad-

as much gas has escaped as would be found in the ground by drilling. If now we find a porous stratum which is gas-bearing overlaid by an impervious bed of rock, such as fine-grained shale, quite possibly the ground-water in such a sandstone will exist under artesian conditions and may exert a pressure considerably more than would be exerted by a column of water equal in height to the depth of the well. This, of course, would be determined should a well be drilled into a water-pocket. But if the wells drilled hit gas-pools, the gas would be found to exist under a pressure greater than the depth of the well would imply.

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vanced an idea that petroleum might be produced by the action of water and carbon dioxid on highly heated alkalis. His experiments in the laboratory showed that when hot carbonic acid (CO_2) is brought in contact with hot alkali metals acetylids are formed which, when treated with water-vapor, produce other hydrocarbons resembling petroleum. If, now, it be admitted that deep down in the earth the temperature is high and that alkaline and other metallic beds exist in relative abundance, we would only have to assume that water with carbon dioxid dissolved in it can penetrate to such beds in order to have the necessary hydrocarbons produced.

In 1871 Baysson presented a theory that petroleum has been produced by the action of water-vapor, carbon dioxid and hydrogen sulphide (H_2S) upon hot iron, a theory based upon laboratory experiments whereby hydrocarbons more or less resembling petroleum were actually obtained. He thought it possible that sea-water holding lime carbonate in solution by an excess of carbonic acid may have penetrated to great depths, where it would come in contact with iron sulphide and hot iron at a sufficiently high temperature to bring about the change just named, and therefore all the hydrocarbons of petroleum and natural gas may have been produced in the same way.

In 1877 Mendelejeff gave a new impetus to the chemical theory by espousing its cause and pointing out how hydrocarbons might be derived from different metallic carbides estimated to exist in sufficient quantities far below the surface of the earth. When cast iron is acted upon at a high temperature by water-vapor it is claimed the water is decomposed, the oxygen taken up by the iron and the carbon of the cast iron and hydrogen of the water unite to form some form of hydrocarbons. More recently we have an analogous method brought into commercial use in the manufacture of acetylene gas for illuminating purposes by the action of water on calcium carbide at ordinary temperatures. Here, it seems, both compounds are decomposed, the calcium taking up oxygen and the hydrogen and carbon uniting to form acetylene gas.

In 1877 Cloez obtained hydrocarbons resembling petroleum by the action of sulphuric acid on carbides of iron and manganese, and in 1878 he obtained like results by the action of hot water on the carbide of manganese.

In recent years the French chemist Moissan has obtained many interesting results in connection with his extensive ex-

perimentation with various metallic carbides, some of which experiments have been repeated many times in other laboratories. He found that different metals at high temperatures unite with carbon, forming a series of metallic carbides similar to the way iron in the smelting-furnace unites with carbon producing cast iron. The production of acetylene gas by the action of water on calcium carbide has just been mentioned. Aluminum carbide produces pure methane (CH_4). Other metallic carbides produce various results, including free hydrogen and quite a variation of hydrocarbons. Uranium carbide, it is stated, gave liquid hydrocarbons with an asphalt base. It seems that many different elements have the capacity of absorbing carbon under favorable circumstances and that the carbon thus absorbed may be obtained in one form or another by various processes. Even sticks of phosphorus, bought in the market for chemically pure, have been shown by Keiser and Remsen to contain traces of carbon absorbed during the manufacturing process.

Recent discoveries bearing on the origin of the diamond also may be mentioned. In the Kimberly diamond-field diamonds are found in connection with a basic eruptive rock which has passed through a rich carbonaceous shale. When the importance of this condition was fully realized, about 1886, naturally it was supposed that the carbon came from the shale and was so explained by H. Carvill Lewis in his paper on the subject.[105] Later Derby[106] showed that the South-American diamonds occurred in an acid eruptive rock which probably had never come in contact with shale. More recent discoveries have shown that diamonds occasionally are found embedded in acid eruptives far removed from shale walls, so that it is generally believed eruptive rocks of any description may contain at least traces of carbon. Even Kimberly diamonds are now found below the carbonaceous shale itself, leaving little ground for thinking the carbon came from the shales.

The application, of course, is apparent, namely, that eruptive rocks of almost any description contain traces of carbon held in some form, and that quite likely many of them contain comparatively large amounts of it. With present limitations on our knowledge regarding volcanoes, it is unsafe to state at what depths such lavas originated, and whether or not groundwaters could reach them, but it would seem reasonable to

105. Lewis, H. Carvill: "Origin of the Diamond," Science, vol. 8, p. 345. 1886.
106. Derby, O. A.: Science, vol. 9, p. 57. 1887.

suppose that the crystalline rock masses below the stratified rocks contain sufficient quantities of carbon to produce large amounts of oil and gas should conditions be favorable for the conversion of such carbon into such forms. Further, it may be added that recent observations tend to show ground-water more nearly universally present in lava and other crystalline rocks than was formerly supposed, which view, if correct, would make the chemical theory all the more plausible.

Dr. David T. Day, of the United States Geological Survey, Washington, D. C., is not a strong believer in the organic origin of oil and gas. He was requested to express his views in writing in order that they might be included in this discussion, and accordingly, early in May, 1908, wrote the following letter:

"INORGANIC ORIGIN OF PETROLEUM.

"The most essential evidence in regard to the inorganic origin of petroleum is that given by N. V. Sokoloff (Bull. Soc. Imp. Nat. Moscou, new ser., vol. 3, p. 720, 1890), citing the finding of hydrocarbons in meteorites. The existence of such hydrocarbons seems to admit of only one explanation—that is, inorganic origin. This has led to what may be called the extreme view of the origin of petroleum—that is, that all bitumens are of cosmic origin; that they were formed at the time of the consolidation of the planet and have been emitted gradually ever since.

"What seems a far more acceptable conception of the inorganic origin of petroleum, as I have it in my own mind, may be formulated thus: Electro-metallurgical processes have shown that the compounds of different elements which can exist at the highest temperatures are most frequently *carbides of metals*. The conception is easy that, in the first combinations of elements as the earth cooled, carbides predominated throughout the earth. These carbides suffered decomposition at the surface when, much later in the cooling, the combination of oxygen and hydrogen became possible in the form of water. The reaction of this water upon the carbides led, of course, to the formation of various hydrocarbons which escaped into the atmosphere. As the water penetrated deeper and deeper into the earth the carbides suffered continual decomposition with the formation of gaseous, liquid and solid hydrocarbons, the proportions depending upon the increasing pressure and temperature as the reaction was more and more confined.

"There is no reason to suppose that, if this reaction ever took place, it is not still taking place, as it is not reasonable to suppose that water has succeeded in penetrating to any significant depth beyond what we recognize as the "earth's crust." The irregular temperatures produced by such reactions would

result in volcanic upheavals of greater or less magnitude, depending upon the nature of the carbides attacked by the water and the porosity of the carbides. These factors would determine the rapidity of the reaction and consequent greater or less liberation of heat.

"Until recently the ideas of geologists concerning the temperature of the earth have been fixed by the idea that the internal heat of the earth was due merely to cooling, and the earth student has expected a law of more or less uniform rate of increase in temperature with the depth from the surface. The accurate measurements of recent times have absolutely negatived any uniform rate of cooling, the rate varying significantly with different localities. It is perfectly evident that many other chemical reactions due to hydration of minerals, and other processes liberating heat, are particularly active in one portion of the earth's crust and not in another; hence the phenomenon of geyser action, hot springs, etc.; but the more powerful reaction of water with carbides is a more satisfactory solution for vulcanism, and the presence of hydrocarbons in volcanic gases is thus most simply explained.

"This, in brief, is my own conception of the inorganic theory. One observation, made by myself in 1897, and which has since been the subject of considerable experimental work by myself and others, is that when petroleum traverses finely porous material, such as shales, the petroleum becomes simpler the farther it travels; that is, that the more viscous materials are left behind. From this point of view, the Pennsylvania petroleum must have traveled far from its original source, and this explanation is convincing to myself that Pennsylvania petroleum at least did not originate in Devonian shales. It is easy from the inorganic theory to account for such extensive migration of oils as come from considerable depths, first through fissures, then occasionally through the finely divided material, so that we have, at the surface, some petroleums, such as Texas and California, much in their original condition, and others, like those in Pennsylvania and Kansas and in the southern Midcontinental field, showing evident results of diffusion between their starting-point and the surface.

"When we note the ease with which petroleum itself diffuses, and when we note that it could not possibly remain for any time in granitic rocks, where every few feet we find cleavages through which petroleum can diffuse with the greatest ease, we find in the inorganic idea relief from the almost impossible conception that petroleum can have existed in a porous earth's crust since a Lower Silurian time, when we have optical evidence that it is continually escaping to the atmosphere. The essential reason why no accumulations of oil are found in igneous rocks is simple in the light of Mrazek's idea that petroleum accumulations are only possible where the pores of sedimentary rocks have been sealed by *moisture* sufficient to make

an impervious cover. It is evident that moisture is the only efficient cover for an oil-field."

Here, as in many other instances of nature study, we find a possible way according to which certain results may have been produced. The discovery of such a possibility by no means renders it certain that nature used such a method. Having discovered the possibility, the question naturally arises: Is this possibility probable?

ORGANIC THEORY.

By the term organic theory for the origin of oil and gas should be understood a belief that oil and gas originated in some way from organic matter by its partial decomposition under water, or in the rocks of the earth from which oxygen of the air is totally or partially excluded. Expositions of this theory have been published in so many places that it need here only be referred to in a general way, or outlined very briefly.

When organic matter, either animal or vegetable, is subjected to partial decomposition away from oxygen of the air, the decomposition is principally along the lines of molecular disintegration, complex molecules breaking down resulting in the formation of two or more less complex molecules. In general, the molecular structure of plant and animal tissue is very complex. Decomposition processes tend to simplify such structure by the formation of two or more simpler molecules. These decomposition products necessarily are exceedingly varied and usually are obtainable in the form of mixtures of such varied molecules. Often some of them are the identical hydrocarbons constituting oil and gas, each of which, particularly the former, is a complicated mixture of various molecules. We have a familiar example of such changes in the production of ordinary marsh-gas. Leaves of trees and blades of grass falling beneath the surface of the water in stagnant pools gradually decompose. The mud at the bottoms of the pools is made black by the carbon set free, and along with other products of partial decomposition, one is produced which in part is held in place by the mud at the bottom of the pool, and in part rises to the surface in bubbles, which may be caught for examination if desired. Everybody is familiar with this condition. In winter, when the surface of the pool is covered with ice, the gas thus generated is gathered in big bubbles, and people skating on the ponds sometimes amuse themselves by drilling holes through

the ice and setting fire to the gas as it escapes. The name marsh-gas is given to the product because it is found in marshy places. The fact that this name has been incorporated into the language of organic chemistry and used the world over by being applied to a great series of hydrocarbons, the marsh-gas series, shows the thinking person how wide-spread such gases are.

In many places throughout portions of America and Europe covered with a mantle of glacial material, gas in varying quantity has been found. For example, during the summer of 1891 a party was drilling a well near Letts, Iowa. At a depth of between 100 and 200 feet, and while still in the glacial material, he came upon a small volume of gas which burned readily and seemed to have all the properties of natural gas. It seems that no chemical analysis was made of it, but from its general qualities there is no room to doubt its being practically the same as other natural gas. The quantity was sufficient to induce men of means to form a company and pipe the gas into the village, where it was used for a time for domestic purposes. Likewise, a few miles north of Des Moines, in 1887, a similar well obtained a similar quantity of natural gas from the glacial material. At this place a well was sunk hundreds of feet below the bottom of the glacial material with entirely negative results, the supply coming entirely from the glacial material. This same glacial material has in it in certain places comparatively large quantities of organic matter, and it would seem we are compelled to admit that the gas in each of these two places was produced by a partial decomposition of such organic materials. Could the sum total of gas already discovered in glacial material be bunched together it would form a very considerable amount, and would be well worth utilization. It is probable that in future time like amounts will be discovered in areas not yet penetrated by the drill.

Now, if organic matter is decomposing before our eyes in this manner, forming a complex series of hydrocarbons, some of which are gaseous in nature, the question may well be asked: Why not account for the large bodies of hydrocarbons in a similar manner? Observation shows that shale-beds and sandstones and limestones, practically of all geologic ages, contain varying amounts of organic matter. Indeed, we often have shale-beds containing so much oil material that it becomes profitable to distil such oil in commercial quantities. It is an

interesting point in history that such distillations were made in large quantities in America and Europe previous to the commercial utilization of petroleum, and even at the present time this industry is carried on in some parts of the world. It is true it may be argued that the oil got into these shales by rising from below after having been produced according to the chemical theory. Probably, however, most observers would look upon this as straining a contention beyond reasonable belief.

Some of the advocates of the chemical theory for the origin of oil and gas argue that the amount of such products now obtainable, added to the amount which probably has been dissipated through surface seepages, is entirely too great to have originated according to the conditions of the organic theory. The writer confesses that at one time such a contention appeared to him to be a difficulty. A more extended observation, however, on the amount of organic matter entombed in the stratified rocks and now being embedded in the same as they are forming, has entirely removed such a difficulty from his mind. Few people realize the vast amount of organic matter annually carried down to the ocean by surface drainage. Vegetation covers practically the entire dry land area of the earth and has done so throughout all geologic time. Varying climatic conditions and other influences doubtless have made a corresponding variation in the richness of organic materials in different rock masses. But when all allowances are made for such variations, it remains that the amount of organic matter thus entombed is and has been enormously great. And such matter need not be confined to vegetation, for our ocean-water is teeming with animal life. Speaking broadly, it is well known that animals subsist on vegetation, and that the constant addition of food matter to the ocean-water for the ocean fauna comes from vegetation, as plants are the great agents for changing inorganic matter into organic matter. When it is recalled how universal the presence of animal life is throughout ocean-water, and that such animals must live largely on organic matter, some conception of the enormous amount of organic matter carried to the ocean may be obtained. These ocean animals die, and portions of their tissues are consumed by other animals. But in the aggregate vast proportions subside and become engulfed in the silt which ultimately becomes rock. If this is true at the present time, likewise it has been true

throughout geologic time. If it is true for masses of stratified rock now existing, likewise it has been true for masses of stratified rock removed by erosion during geologic time. If one will put himself into a position which makes it necessary to give a reasonable account for the whereabouts of all this vast quantity of organic matter, animal and vegetable, which has been engulfed in the masses of stratified rock, one will find that the quantity of oil and gas now available is all too small, rather than too large, for such accounting. The probabilities that oil and gas have been escaping into the air throughout geological time the same as they now are in reality does not affect the problem, because such escapes doubtless have been no greater relatively than has been the wearing away of similar rocks during the same time.

The interesting relations between productive sandstone and shale-beds in the Midcontinental oil-field are of considerable importance in this discussion. The conditions already explained in detail in the Neosho river valley at Chanute may be cited. Here we have gas existing under a pressure more than 300 pounds to the square inch in a sandstone underlying an oil-producing sandstone with from 30 to 40 feet of shale between. If, now, there were a passage-way connecting these two productive sands, it follows that as soon as a drill reached the upper oil-sand, gas pressure from the lower sand would produce a gusher. Experience shows just the reverse to be the case. Many oil-wells were drilled with none of them having a gas pressure sufficient to make a flowing well. The question at hand is as to how these two materials could have worked their way upward from a greater depth and arranged themselves in the relative positions in which we now find them. How could the oil have gotten above the gas and at the same time be separated completely from it?

The conditions at Chanute are not essentially different from those found elsewhere. Already well No. 1 belonging to the Kansas Crude Oil Company, near Humboldt, has been described as having an oil-producing sand overlying a gas-producing sand. In the history of that well the oil did not begin flowing until the drill had penetrated the gas-sand below. Many cases of this kind are known, widely scattered over the entire area of the Midcontinental field, a particularly good example in Oklahoma being along Hogshooter creek, where good oil-wells abound, the oil being obtained from the sandrock

overlying a gas-sand with from 20 to 60 feet of shale between the two sandrocks. Here the flow of gas is stronger than at either place just named. Some of the oil-wells have gas enough in them to make them flow for a time without having the drill reach the gas-sand below, but the gas pressure is so enormously great and the wells are so strong that, should a gas-well be brought in without casing off the oil above it would drive the oil into spray in a very different manner from the comparatively mild flowing properties possessed by such wells as do actually flow. Here, then, is another instance of a sandstone being filled with a gas underlying a second sandstone filled with oil, with what would seem to be positive evidence that no passage-ways whatever connect the two. How, now, can it be possible that both of these materials came from great depths below?

It may be stated here that different men at different times have believed that the oil and gas of this Midcontinental field originated in deeper lying Silurian rocks, and have tried to explain the same by the assumption that a certain series of vertical fissures provided escaping channels for the oil and gas manufactured below. In fact, considerable money has been spent in prospecting based on this belief. Wells have been located where, according to such parties, they would be most likely to catch the oil in its upward migration. Unfortunately all such attempts have been unsuccessful, although a good many thousands of dollars have been spent.

In the Russian oil-fields, already referred to earlier in these pages, oil and gas occur in a loose, uncemented sand of the Tertiary age. Mr. A. Beebe Thompson, in his most admirable book, The Oil Fields of Russia, has given us a good description of the details under which oil and gas exist. He has reached the conclusion unequivocally that, for this most wonderful of all oil-fields, the hydrocarbons were produced in sands practically where now found. In a lengthy discussion he shows how organic matter may have been imbedded in the sand beneath the ocean-water, and under the influence of anerobic bacteria decomposition would take place, breaking down the complex organic molecules, producing the simpler molecules of oil and gas.

Another series of observations world-wide in extent may be mentioned. In our mining operations explodable gases are almost universally present in coal-mines, the only mines we have

in rocks regularly laden with organic matter, while not a single instance is on record of hydrocarbon gases in mines confined to the crystalline rocks. The explanation for absence of such gases in crystalline rocks given by Mrazck and quoted above by Doctor Day is unsatisfactory to students of crystalline rocks, for it is well known that enough "quarry sap" exists in all rocks in a measure to hold in oils and gases were they present. In fact recent experiments by Chamberlin show that other gases do exist in crystalline rocks in relatively large quantities, and deep mines, in Cripple Creek particularly, are bothered with nitrogen gas badly, but not with hydrocarbons. (See chapter VII, this report.)

Now, it is very difficult to understand the universal presence of hydrocarbons in coal-mines, with practically no other gases with them, and the frequent presence of nitrogen and other gas in crystalline rock mines, with no hydrocarbon gas present, if the gases were generated far below the surface and gradually worked their way outwards. Advocates of the inorganic origin of oil and gas should give a more satisfactory explanation of the conditions above named than they have yet been able to do, or admit the difficulty in the way.

Recently considerable interest has been awakened by the discovery that many of the petroleum products have the power of rotating the plane of polarization of light in a manner similar to the way sugar, tartaric acid, lactic acid and other organic compounds produce the same effect. This property of petroleum has been used by Prof. Karl Engler, of Karlsruhe, Mr. M. A. Rakusin, petroleum engineer of Moscow, and others, in their arguments in favor of petroleum being of organic origin. In an article recently published[107] by Dr. Max Reinhard and N. Botez, the subject is mentioned as follows: "The question of the optical activity of crude oils and their distillation products plays an important role regarding the origin of petroleum. Particularly, Professors Engler and Rakusin see therein a strong argument for the organic origin of these valuable products, and which at the same time seem to favor animal origin of these materials."

The products of distillation of the Kansas oils were studied with reference to their rotary power by Mr. Frank Brock under the direction of Professor Bushong, and the results are included in the chapter on the chemical properties of Kansas

107. Revue du Petrole, January 8, 1808, Bucharest, Roumania.

It will be seen by reference to that chapter that our sas oils are decidedly active optically, and, so far as this have a bearing on the question in hand, there is strong e ence herein favorable to the organic origin of Kansas pe- t ums.

It is believed by the writer that a careful examination of the various oil-fields in America, and even those of Russia and elsewhere, will reveal a series of complicated conditions which in general may be given a much more likely explanation by assuming that the oil and gas originated in the rock masses approximately where found than by assuming that they originated at much greater depths. By this it is not meant at all that the oil in the Carboniferous sandstones in the Midcontinental field originated in these same sandstones, or that the oil in the Trenton limestone of Indiana and Ohio originated in that limestone, but rather that the oil and gas of the Midcontinental field originated principally in the great complex of sandstones, limestones, and shales constituting the Coal Measure rocks of this area; that the oil and gas of the Trenton limestone originated in a like manner in the complex of stratified rocks in that vicinity, and so on, at least for a great majority of oil- and gas-pools now known. It should be remembered also that if there are two or more possibilities, likewise there may have been two or more methods of origin. Also, that if there are difficulties in accounting for the comparatively slight migrations of oil and gas in the Midcontinental field according to the organic theory, necessarily there must be much greater difficulty in accounting for similar migrations if one adopts the chemical theory. This latter statement is made with emphasis, because no matter how they originated the question of their migrations within rock masses is one about which we know all too little and on which there should be a great deal of experimentation; but the difficulties of accounting for proper migrations are less by the organic theory than by the chemical theory.

Since the above discussion on the origin of oil and gas was written my attention has been called to a recent article in the Chemisches Zentralblatt, which gives an abstract of an address on this subject delivered by Dr. C. Engler, of Germany, which address is so important that it is thought desirable to publish the abstract in full. At my request Prof. F. W. Bushong, of the University of Kansas, made a translation of the paper, which is hereto appended in the form of a special sheet after the body of this report was issued from the press.—E. H.

THE ORIGIN OF PETROLEUM.

BY DR. C. ENGLER.

An abstract of an Address Before the Verein Deutscher Chemiker.
Translated from the Chemisches Zentralblatt, 1908, vol. 2, p. 976, by Prof. F. W. Bushong.

"The last year has witnessed an unmistakable clarification of opinions on this subject. The speaker describes the development of both the inorganic and organic hypotheses and the prominence recently acquired by the latter. In the following abstract the more important generalizations regarding the changes of organic substances in their transition into petroleum are presented.

"The first phase in the process of bitumenization consists of fermentation or decay, as a result of which the albuminous matter and the substance of the plant-cells in general disappear. Only the fatty matters, including waxes and small quantities of the more stable substances, among which are to be found fatty acids and some albumious matter, remain undecomposed.

"The second phase, which may have already begun in part during the first phase, is the saponification of fat glycerides with the separation of free fatty acids through the action of water, or ferments, or of both. To what extent also wax esters may be split up hydrolytically is not fully determined.

"In the third phase the splitting off of carbonic acid from the acids or esters, and of water from alcohols, oxyacids, etc., occurs, with the resulting formation of high molecular hydrocarbons which may still contain admixtures of oxygen compounds (ozokerite, Seeschlickbitumen).

"In the fourth phase the formation of a mixture of liquid hydrocarbons takes place energetically with the splitting up of high molecular intermediate substances into lighter liquid and gaseous products. To bring about these reactions an expenditure of energy was necessary, which, at but a slightly elevated temperature, can only be supplied through long periods of time. Experiments have shown that, with proper regulations of temperature and pressure during distillation, high molecular fats and hydrocarbons may be split up at will—at moderate temperatures and pressures into intermediate oils, and at high temperatures and pressures into lighter oils. There is also a difference whether the pressure is brought about through vapors due to the reaction, or through gases which take no part in the reaction.

"The variations of temperature which occur in the crust of the earth

during the course of time may bring about another phase—the polymerization and addition of unsaturated residues—producing high molecular products, such as lubricating oils.

"The changes occurring during these phases may overlap. Some substances may be converted into end-products while others are still in transition; for example, the ethylenes. Others again may not yet have begun to change; for example, the wax esters. Petroleum deposits may, therefore, be looked upon as continually undergoing transformation.

"The different groups of hydrocarbons may have originated somewhat as follows:

"*First.* The methane series (homologues of marsh-gas) are formed directly from bitumen; that is, from the intermediate products formed in part from fatty radicals by loss of carbon dioxide (high molecular hydrocarbons with radicals of free fatty acids and their esters).

"*Second.* The ethylene series (olefines). In so far as the lower members occur, they must have been formed directly. On account of their unsaturated nature and their tendency to unite and to polymerize, they in time disappear, but to some extent are re-formed during the distillation of petroleum, especially in the high-boiling portions; for example, in the cracking process.

"*Third.* The naphthene series. The relatively larger quantities of naphthenes are probably rather indirectly formed than directly by the decomposition of hydroaromatic olefines by heat and pressure, according to Kraemer and Aschan. Experiments of the speaker, together with Eberle, confirm the results of Aschan. Hexylene (methyl-propyl-ethylene) of density of 0.6870 and melting-point 67° to 68°, after heating in a sealed tube for fourteen days at 360° to 365°, shows a density equal to 0.7282° and melting-point 67° to 240°, and a lessened bromine absorption. According to Rogowski, propylene heated to from 400° to 405° is more than half converted into a gas containing tri-methylene which no longer absorbs bromine. The remaining unsaturated hydrocarbons can polymerize to lubricating oils.

"*Fourth.* The lubricating oils (difficultly separable mixtures of saturated and unsaturated hydrocarbons of the methane, naphthene, ethylene and acetylene series, etc.) may originate by direct decomposition of fatty esters through rapid or slow change or through self-polymerization and addition of unsaturated hydrocarbons which were formed through the breaking up of organic residues with or without catalyzers,* or by synthesis from unsaturated components, such as styrol and allyl alcohol. Benzene and its homologues may have been formed at moderately high temperatures by the decomposition of fats or from the substituted fatty acids derived from albuminous substances; or also by ring formation from aliphatic compounds.

"There is very strong evidence in favor of ferment action only in the first and not in the last stages of transformation, and, on the other hand, of violent action in the closing processes of formation of the protopetroleums.

* Ethylene hydrocarbons such as amylene and hexylene were found by Rosenquist to go over into high boiling viscous oils when warmed under pressure, even without the use of aluminum chloride.

ORIGIN OF THE OPTICALLY ACTIVE CONSTITUENTS.

"The contributions of the decomposition products of albuminous matters, as well as the remains of resins, balsams, terpenes, tannins, etc., to the optical activity of petroleum are only of minor importance. This activity is rather due to the presence of a single substance, because the fractions of petroleum which show the maximum optical activity, from whatever fields they are derived, boil at about the same temperatures. In almost all oils the content of optically active substances begins to appear in the fractions between 200° and 250°, and above this reaches a variable maximum value and then falls rapidly. In the case of oil from Pechelbron, the speaker, together with Lederer, has recognized two maxima, one of +0.5° at 69° to 76.5° under 17 mm. pressure, and another of 6.6° at 281° to 291° under 13 mm. pressure. Between these two points several fractions were inactive. If the same oil is distilled under ordinary atmospheric pressure there is a marked change in optical activity, due to compensation or racemization. The two maxima remain, only the inactive portions are shifted to lower fractions. Still more surprising is the fact noted by the speaker and Bartnitzki that petroleum from Java is leavo-rotatory in its lower fractions (—4.8° below 190°), higher up it is inactive, and still higher it becomes dextro-rotatory. These observations are most easily explained on the supposition of Marcusson that cholesterin is the substratum which causes the optical activity of petroleum.

"The speaker supported this hypothesis by the following results and considerations: The optical maxima of petroleum from different sources appeared, generally, in fractions of the same boiling-point which is the same as that found in the products obtained from cholesterin. The speaker, together with Hullard, found that cholesterin gives products of different boiling-points depending upon the manner of distillation. In vacuum it distills undecomposed and remains leavo-rotatory. When distilled rapidly at ordinary pressure, the product may be either dextro- or leavo-rotatory. After distillation is carried on for an hour a noticeable inversion of the rotation from left to right occurs at from 300° to 350°. When cholesterin is distilled by itself under pressure or with fish-oil, according to Marcusson, dextro-rotatory products are obtained. If this distillation under pressure is repeated the activity decreases or disappears at the corresponding temperature, even without distillation. In like manner phytosterin distills in vacuum unchanged and without loss of leavo-rotatory power. When not too rapidly distilled under atmospheric pressure strongly dextro-rotatory distillates are obtained. (Twenty grams cholesterin distilled three times gave products of +112° and +128° rotation.) Water was constantly obtained as a decomposition product. It is by no means necessary to assume that the highly active distillates of cholesterin contain a product free from oxygen. An ether of cholesterin might be present. R. Albrecht found in Galician petroleum of +25° rotation 0.3 per cent. oxygen. Since a petroleum so strongly active as that of Galicia contains only one per cent. of the most highly active fraction, it follows that small quantities of the substratum, choles-

terin, are sufficient to account for the activity of petroleum. On account of the stable character of cholesterin and phytosterin derivatives a natural process of concentration of the optically active substances takes place, or has taken place, during the phases of transformation. Artificial mixtures of inactive components, Kaiser oil, lubricating oil or vaseline oil, and mineral wax (inactive artificial crude oil) made active by the addition of the dextro-rotatory fraction from slowly distilled cholesterin (active artificial crude oil), when subjected to fractional distillation first under one atmosphere pressure and then in vacuum like the optical activity of natural petroleums show optical maxima in the fraction 240° to 290° under 14 mm. pressure. Further, the maxima of the dextro-rotatory high-boiling fractions from Javanese petroleums agree with those of cholesterin distillates, and the leavo-rotatory portions of that oil are obtained within the same limits as the leavo-rotatory portions of cholesterin distillates. The speaker, together with Lederer, succeeded in transforming leavo-rotatory fractions from Javanese petroleum into dextro-rotatory and also optically inactive fractions into dextro-rotatory products in the same manner as was possible with cholesterin distillates.

"The speaker believes that no petroleum is entirely inactive, and recommends that apparently inactive fractions be tested as to whether, when heated 350° to 360° in sealed tubes they will not become dextro-rotatory.

"So far as the origin of the principal petroleum deposits are concerned, the inorganic hypothesis is therefore no longer tenable."

CHAPTER VI.

COMMERCIAL CONDITIONS OF OIL AND GAS.

BY ERASMUS HAWORTH.

Oil.

THE total production of oil to the close of the calendar year 1907 is given in the enclosed tables. They are so arranged that little, if any, explanation is needed. It will be noted that oil has been marketed in Kansas for many years, 500 barrels having been reported as early as 1889. The yield gradually increased to and including the year 1896, when a total of 113,571 barrels were produced. From this it gradually declined to 85,215 barrels in 1899. The new development set in shortly after this and the production rapidly increased to a maximum, in 1904, of 4,250,779 barrels, since which time the production has gradually declined. For the year 1905 the Prairie Oil and Gas Company bought in Kansas 3,244,062.96 barrels; for 1906, 3,128,287.17 barrels, and for 1907, 1,696,-428.85 barrels. The independent refineries and consumers of fuel-oil consumed an amount not determined with exactness, but probably more than half a million barrels per year, which should be added to the above figures.

During this period the production of oil in what is now the state of Oklahoma has gradually increased from the first developments, nearly ten years ago, to and including the year 1907. Developments south of the Kansas state line were very rapid and satisfactory in 1906 and 1907. Most of the purchasers of oil disregarded the state line in their commercial operations, and as a result it is easier to obtain figures for the entire Midcontinental field, including Kansas and Oklahoma, than for each one separately. In 1904 the production of the entire field was only a little over five and one-half million barrels, showing that but little drilling had been done south of the state line at that time. For the year 1905, however, it aggregated fully 12,000,000 barrels; in 1906, nearly 22,000,000 bar-

rels, and in 1907 the magnificent amount of 47,556,905 barrels, making the Midcontinental field the most productive field in America.

TABLE SHOWING PRODUCTION OF PETROLEUM IN KANSAS FOR 1889 TO 1907, INCLUSIVE.

Figures for 1889 to 1896, inclusive, are taken from the reports of the U. S. Geological Survey.

Year.	Barrels.	Year.	Barrels.	Price per barrel.	Value.
1889.....	500	1894.....	40,000	48 cts.	$19,200 00
1890.....	1,200	1895.....	44,430	64 "	28,435 20
1891.....	1,400	1896.....	113,571	63 "	71,549 73
1892.....	.....	1897.....	90,000	60 "	54,000 00
1893.....	18,000	1898.....	*88,000	$2 00	176,000 00
		1899.....	85,215	75 cts.	52,167 09
Total.....	21,100	1900.....	91,294	80 "	79,035 20
		1901.....	169,197	80 "	135,357 00
		1902.....	322,023	90 "	289,820 70
		1903.....	1,018,199	$1 10	1,120,018 90
		1904.....	4,250,779	97 cts.	4,123,245 63
		1905.....	3,750,250	60 "	2,250,150 00
		1906.....	3,627,375	41 "	1,867,223 75
		1907.....	2,125,275	40 "	850,110 00
		Totals.....	15,836,708	.....	$10,625,633 71

*Refined.

PRICES.

The price of oil has varied greatly. In 1902 it averaged about 88 cents a barrel in Kansas; in 1903, $1.04; in 1904, 97 cents; from which time it dropped rapidly to 41 cents for the best oil throughout the entire Midcontinental field, from which point it did not vary more than a cent a barrel throughout the entire two years of 1906 and 1907. The heavier grades of oil uniformly brought a lower price. A short discussion of this subject has already been given in earlier pages of this volume.

Gas.

The tables here included show our best approximation of the total value of the gas produced in Kansas, and also the Midcontinental field. At the present time gas is much more in demand in Kansas than in Oklahoma. This is due principally to the presence of large factories in Kansas and to pipe-lines carrying gas to large cities, such as Kansas City, Topeka, Leavenworth, Atchison, St. Joseph, etc. In Oklahoma few factories are yet built and legal conditions are such that no gas has yet been piped out of the state. For these reasons figures for production of natural gas in the two states will show a large preponderance of Kansas over Oklahoma, while the facts

are that there is much more gas developed and shut in in Oklahoma than in Kansas.

In determining the value of gas a number of difficulties are encountered, the chief of which is that it is so nearly impossible to arrive at a satisfactory valuation per unit to put upon the gas. For example, in every town reached by pipe-lines belonging to the Kansas Natural Gas Company the consumer pays a minimum of twenty-five cents per thousand cubic feet of gas consumed for domestic use, and about ten cents for factories, measured at a pressure of about four ounces above normal atmospheric pressure. At least a portion of this same gas is bought by the Kansas Natural Gas Company at something under three cents per thousand cubic feet. What, now, should be the price per thousand for such a consumption? It is evident that the consumer would not do without it even though he had to pay more than twenty-five cents a thousand; and likewise it is true that the Kansas Natural Gas Company has no gas for sale at three cents a thousand.

If we compare the fuel value of gas with coal we have another difficulty in the way, which is hard to overcome, in that we do not know how much gas is equal in value to a ton of coal for consumption. The matter of luxury comes in and makes the use of coal prohibitive for those who can use gas. In the large factories gas is so much more convenient and is so readily used that here again its value is greater than its mere heat-producing capacity, because the labor put upon it in process of consumption is much less than that put upon coal or other fuel.

In their chapter on "Chemical Composition of Gas," Professors Cady and McFarland give a table showing that much of our gas has an actual heat-producing value of 930 British thermal units per cubic foot of gas measured at standard atmospheric pressure and temperature. By comparing this with good coal having 13,000 British thermal units per pound, we find that it takes about 28,000 cubic feet of gas to equal one ton of such coal. If the coal used in the comparison is of less value, the number of cubic feet to form such an equivalent would be greatly decreased. Here, also, we have another consideration of great importance, namely, the degree of combustion. It is well known that none of our furnaces for burning coal produce perfect combustion. Where gas is burned, likewise sometimes the combustion is imperfect; but, in general, it is very much more nearly perfect than the combustion of

coal. All of this is in favor of the gas, and preference for it should be given when the two kinds of fuel are compared.

It is common with the practical, every-day man to say that 20,000 cubic feet of gas equal one ton of coal in heat value. It will be seen that in order to make this true where perfect combustion of coal is obtained we should have a coal producing only 9300 British thermal units per pound. It is probable, therefore, that with many furnaces wherein coal combustion is very imperfect 20,000 feet of gas will produce as much steam, or as much heat, as a ton of coal, but for stationary boilers supplied with good furnaces the amount would range from 23,000 to 25,000.

Another consideration of no small importance, and yet one which is entirely overlooked by most purchasers of gas, is the matter of pressure at which gas is measured. It is now customary in most places in Kansas to sell gas by meter measurement. Probably more than two-thirds of the customers pay no attention whatever to the matter of pressure at time of measurement, many of them perhaps not even knowing that this is of any importance. Gas-meters are constructed in such a way that gas is measured by volume. It is well known that if the pressure of any gas be doubled its volume will be halved. If, now, one should buy a thousand cubic feet of gas measured at the pressure of one atmosphere and a second thousand feet measured by the same meter at two atmospheres, the second thousand feet would be nearly, if not quite, double the first in actual value, and would expand to 2000 feet if the pressure were reduced to one atmosphere. Within the limits of our gas-field the atmospheric pressure is usually somewhere between fourteen and fifteen pounds per square inch. If a large manufacturing establishment should contract for gas to be measured at fifteen pounds above the atmosphere it would get nearly double the amount of gas that would be charged to it if it were measured almost at the atmospheric pressure.

In most of our cities, towns and villages where gas is used for domestic purposes it is measured at about four ounces above atmospheric pressure. If, now, the same were measured to them at about fifteen pounds pressure, they would get practically double the amount.

The Pittsburg Meter Company, of East Pittsburg, Pa., has prepared a table showing what multiplier ought to be used for gas measurements above eight ounces in order to bring the

TABLE SHOWING VARIATION IN GAS MEASUREMENTS.

PITTSBURG METER CO. EAST PITTSBURG PA.

MULTIPLIERS TO BE USED FOR GAS AT PRESSURES GREATER THAN EIGHT OUNCES.

LBS.	MULT.	LBS.	MULT.	LBS.	MULT.	LBS.	MULT.	LBS.	MULT.	LBS.	MULT.	LBS.	MULT.
1	1.032	16½	2.032	32	3.032	47½	4.032	63	5.032	78½	6.032	94	7.032
1½	1.064	17	2.064	32½	3.064	48	4.064	63½	5.064	79	6.064	94½	7.064
2	1.097	17½	2.097	33	3.097	48½	4.097	64	5.097	79½	6.097	95	7.097
2½	1.129	18	2.129	33½	3.129	49	4.129	64½	5.129	80	6.129	95½	7.129
3	1.161	18½	2.161	34	3.161	49½	4.161	65	5.161	80½	6.161	96	7.161
3½	1.193	19	2.193	34½	3.193	50	4.193	65½	5.193	81	6.193	96½	7.193
4	1.226	19½	2.226	35	3.226	50½	4.226	66	5.226	81½	6.226	97	7.226
4½	1.258	20	2.258	35½	3.258	51	4.258	66½	5.258	82	6.258	97½	7.258
5	1.290	20½	2.290	36	3.290	51½	4.290	67	5.290	82½	6.290	98	7.290
5½	1.322	21	2.322	36½	3.322	52	4.322	67½	5.322	83	6.322	98½	7.322
6	1.354	21½	2.354	37	3.354	52½	4.354	68	5.354	83½	6.354	99	7.354
6½	1.387	22	2.387	37½	3.387	53	4.387	68½	5.387	84	6.387	99½	7.387
7	1.419	22½	2.419	38	3.419	53½	4.419	69	5.419	84½	6.419	100	7.419
7½	1.452	23	2.452	38½	3.452	54	4.452	69½	5.452	85	6.452	100½	7.452
8	1.484	23½	2.484	39	3.484	54½	4.484	70	5.484	85½	6.484	101	7.484
8½	1.516	24	2.516	39½	3.516	55	4.516	70½	5.516	86	6.516	101½	7.516
9	1.548	24½	2.548	40	3.548	55½	4.548	71	5.548	86½	6.548	102	7.548
9½	1.581	25	2.581	40½	3.581	56	4.581	71½	5.581	87	6.581	102½	7.581
10	1.613	25½	2.613	41	3.613	56½	4.613	72	5.613	87½	6.613	103	7.613
10½	1.645	26	2.645	41½	3.645	57	4.645	72½	5.645	88	6.645	103½	7.645
11	1.677	26½	2.677	42	3.677	57½	4.677	73	5.677	88½	6.677	104	7.677
11½	1.710	27	2.710	42½	3.710	58	4.710	73½	5.710	89	6.710	104½	7.710
12	1.742	27½	2.742	43	3.742	58½	4.742	74	5.742	89½	6.742	105	7.742
12½	1.774	28	2.774	43½	3.774	59	4.774	74½	5.774	90	6.774	105½	7.774
13	1.806	28½	2.806	44	3.806	59½	4.808	75	5.806	90½	6.806	106	7.806
13½	1.839	29	2.839	44½	3.839	60	4.839	75½	5.839	91	6.839	106½	7.839
14	1.871	29½	2.871	45	3.871	60½	4.871	76	5.871	91½	6.871	107	7.871
14½	1.903	30	2.903	45½	3.903	61	4.903	76½	5.903	92	6.903	107½	7.903
15	1.935	30½	2.935	46	3.935	61½	4.935	77	5.935	92½	6.935	108	7.935
15½	1.968	31	2.968	46½	3.968	62	4.968	77½	5.968	93	6.968	108½	7.968
16	2.000	31½	3.000	47	4.000	62½	5.000	78	6.000	93½	7.000	109	8.000

BAROMETER 30.45 INCHES AT SEA LEVEL.
TEMPERATURE 60° FAH.

volume of gas up to what it should be, provided the contract is made for eight-ounce pressure. This table is included herewith and will prove to be one of unusual interest to purchasers of gas. Of course, the difference between four ounces and

We do not regard this analysis as having any particular value, but it is the only one of an Oregon natural gas of which we have any knowledge.

UTAH.

In a report on "Natural Gas near Salt Lake City, Utah," by G. B. Richardson,[152] is an analysis of the gas collected at the wells, 500 to 600 feet deep, in 1894, and analyzed by Prof. J. T. Kingsbury and others:

TABLE No. 25. SALT LAKE CITY GAS.

Methane	22.3
Ethane	37.8
Ethylene	0.7
Carbon monoxid	1.2
Carbon dioxid	0.8
Hydrogen	16.6
Nitrogen	19.7
Oxygen	0.9
	100.0

In commenting on the somewhat remarkable figures of this analysis, F. C. Phillips[153] asserts that the hydrogen determination must be in error. He describes a very delicate method and apparatus by which he tested this gas thoroughly for hydrogen. None was found to be present.

COLORADO.

Few analyses are available of gases occurring in Colorado. Neither of the ones which we have found published are of combustible gases. Their interest lies rather in their high percentage of nitrogen, which is of importance in relation to the Dexter, Kan., and the Princeton, Ill., gases.

Harry A. Lee[154] describes a gas which issues in great quantity from a highly brecciated portion of a great fault fissure-vein, in the Happy Thought mine, near Creede, Colo. The gas is lighter than air, seeking the upper portion of drifts, and is more abundant at times of low barometric pressure, disappearing almost completely when the pressure is high. The outflow or inflow through openings in the breasts of drifts is at times sufficiently powerful to be distinctly audible and to blow the flame of a candle nearly horizontal. An analysis by W. F. Edwards showed oxygen, 3.92 per cent.; nitrogen, 96.08 per cent.

No statement is made as to whether the concentration of

152. Bull. No. 260, U. S. Geol. Surv., p. 481. 1904.

153. Proc. Eng. Soc. of West. Pa. 13, 453.

154. Proc. Colo. Sci. Soc., 7, 163-188.

The following discussions of the development in the Midcontinental field for the years 1904, 1905, 1906 and 1907 are copied bodily from *The Engineering and Mining Journal,* from which publication they were copied into *The Mineral Industry* for the same years, having been written by the author of this chapter.

OIL AND GAS DEVELOPMENT IN THE MIDCONTINENTAL FIELD DURING 1904.

During 1904 oil development in Kansas and the Indian Territory was unusually vigorous. At the beginning of the year less than 1600 wells were producing oil within the entire area; at the close there were fully 4000. The total production of oil during the year was 5,617,527 barrels, of which Kansas gave 4,250,779 barrels and Indian Territory and Oklahoma the remainder. In 1903 the gross output was 1,071,125 barrels (Kansas, 932,214); and in 1902, 368,849 barrels (Kansas, 331,749). During 1904 the daily average for the whole field rose from 9107 barrels in January to 24,353 barrels in December, averaging 15,287 barrels per day for the year. The average price per barrel was 97 cents in 1904, $1.04 in 1903, and 88⅝ cents in 1902.

The most productive areas in Kansas are found principally in Allen, Neosho, Wilson, Montgomery and Chautauqua counties. Early in the year there was great activity in the Bolton field, near Independence, in Montgomery county; also rapid development in all of the other counties named, particularly Chautauqua. By the end of the year activity had moderated to a considerable extent in all parts of Kansas except Chautauqua county.

The new outlying fields that were developed during the year within the state were one in the vicinity of Erie, in Neosho county, and one in the vicinity of Paola, in Miami county, which together gave an output of 14,500 barrels. Some oil developments began about Erie in 1903, but during 1904 a good supply of oil was obtained from many different wells. This has scarcely been marketed at all, on account of a lack of facilities for transportation. Activity about Paola began in earnest in midsummer, 1904, and continued to the end of the year. Here a shallow oil-sand is found at a depth of about 350 feet, which seems to be as productive as the average oil-sand of Humboldt and Chanute. The Standard Oil Company has promised Paola a pipe-line.

from Vancouver, British Columbia.* The results shown are as follows:

TABLE No. 26.

	Point Albino, Canada.	Vancouver, British Columbia.
Methane	96.57	93.56
Ethane	0.00	
Hydrogen	0.00	0.00
Carbon monoxid	0.00	0.00
Carbon dioxid	trace	0.14
Nitrogen	2.69	6.30
Hydrogen sulfid	0.74	0.00
	100.00	100.00

SECTION III.

ANALYSES OF KANSAS NATURAL GAS.

1. Collection of gases.
2. Methods of analysis—calculations, formulæ, etc.
3. Determination of helium, neon, argon, etc.
   - *a.* Apparatus.
   - *b.* Method of analysis.
4. Analytical results.
   - *a.* Data concerning gases analyzed.
   - *b.* Table of analyses.
   - *c.* Discussion of results.
     - Variation in composition.
     - Distribution of constituents.
     - Isohelium and isoparaffin lines.
     - Origin of helium, etc.
     - Conclusions.
5. The heating power of Kansas gas.
   - *a.* Methods of determining.
     - Calculation from analysis.
     - Calorimetric determination.
       - Relative value of results.
   - *b.* Principle and use of the gas calorimeter.
   - *c.* Experimental work on heat values, pipe-line gas.
     - Calorimetric determinations.
     - Analysis of same sample.
     - Calculation of heat value from analysis.
     - Comparison.
   - *d.* Importance of heat determination.
     - Effect of dilution of gas by nitrogen on heat value.
     - Need of laboratory check on both composition and heat value.

Analyses of Kansas Natural Gas.

The work given below was done in the laboratories of the Department of Chemistry of the University of Kansas during the years 1905-1907. A considerable part of the results have already been published in a paper by Cady and McFarland,[157] and the authors have made a number of abstracts from this paper in the present chapter. Additional analyses have been made since this publication, and some calorimetric work has been done.

* Am. Chem. Jour. 16, 1894, p. 416.

157. Jour. of Am. Chem. Soc., 29, 1523-1536 (1907).

the Arkansas river from the Osage lands. This resulted in a great rush to all adjacent lands, both in Cleveland on the south and in the Osage Nation on the north, and at present many drills are in operation on both sides of the river. It is reported that leases there are higher than anywhere else, excepting immediately adjacent to Bartlesville. Development was also carried on throughout the year in the vicinity of Muskogee, Chelsea, Tulsa, Red Fork and Bartlesville.

Later in the year the Secretary of the Interior began to confirm leases within the Cherokee territory, and drilling began immediately with great activity, so that at present derricks are being erected and drills are in operation in many places. A few small areas were leased previously, notably section 12, including nearly all the town site of Bartlesville, which was leased to the Cudahy company; and an area of twelve sections near Chelsea leased to the Cherokee Oil and Gas Company. A part of the town site of Bartlesville was deeded outright, so that the owners can lease or drill at their pleasure. Since Cherokee leases have been confirmed drilling has become very active in the vicinity of the little town of Alluwe, about thirty miles south of Coffeyville, and also at the villages of Dewey and Lenapah, the former being four miles north of Bartlesville and the latter ten miles south of Coffeyville. At the close of November Chelsea had about 96 producing wells, Red Fork 50, Cleveland 10, Muskogee 35 or more, Bartlesville nearly 200, and other points within the Osage territory 75 or 80 more.

At Chelsea and Alluwe the wells are from 300 to 600 feet in depth; at Red Fork and Tulsa from 700 to 1000 feet; at Muskogee 1000 to 1200 feet; at Bartlesville about 1100 to 1400, and at Cleveland 1600 to 1700 feet, the deepest of any in the entire Kansas-Indian Territory field.

Some recent analyses of Kansas oils are given in the table (page 208). The method consisted of distilling the volatile products in fractions, each approximating one-tenth of the original volume, while noting the limiting temperatures in Centigrade and the specific gravity of each fraction in Baumé degrees.

The Standard Oil Company, under the title Forest Oil Company, but later changed to Prairie Oil and Gas Company, entered the field in 1895; in 1897 it built a 500-barrel refinery at Neodesha. Within the last two years it has built a refinery at Kansas City, Mo., with a pipe system branching into Kansas

rels, and in 1907 the magnificent amount of 47,556,905 barrels, making the Midcontinental field the most productive field in America.

TABLE SHOWING PRODUCTION OF PETROLEUM IN KANSAS FOR 1886 TO 1907, INCLUSIVE.

Figures for 1889 to 1896, inclusive, are taken from the reports of the U. S. Geological Survey.

YEAR.	Barrels.	YEAR.	Barrels.	Price per barrel.	Value.
1889.....	500	1894.....	40,000	48 cts.	$19,200 00
1890.....	1,200	1895.....	44,430	64 "	28,435 20
1891.....	1,400	1896.....	113,571	63 "	71,549 73
1892.....	.....	1897.....	90,000	60 "	54,000 00
1893.....	18,000	1898.....	*88,000	$2 00	176,000 00
		1899.....	85,215	75 cts.	52,167 00
Total.....	21,100	1900.....	91,294	80 "	79,035 20
		1901.....	169,197	80 "	135,357 60
		1902.....	322,023	90 "	289,820 70
		1903.....	1,018,199	$1 10	1,120,018 90
		1904.....	4,250,779	97 cts.	4,123,245 63
		1905.....	3,750,250	60 "	2,250,150 00
		1906.....	3,627,375	41 "	1,367,223 75
		1907.....	2,125,275	40 "	850,110 00
		Totals.....	15,836,708	.....	$10,625,633 71

*Refined.

PRICES.

The price of oil has varied greatly. In 1902 it averaged about 88 cents a barrel in Kansas; in 1903, $1.04; in 1904, 97 cents; from which time it dropped rapidly to 41 cents for the best oil throughout the entire Midcontinental field, from which point it did not vary more than a cent a barrel throughout the entire two years of 1906 and 1907. The heavier grades of oil uniformly brought a lower price. A short discussion of this subject has already been given in earlier pages of this volume.

Gas.

The tables here included show our best approximation of the total value of the gas produced in Kansas, and also the Midcontinental field. At the present time gas is much more in demand in Kansas than in Oklahoma. This is due principally to the presence of large factories in Kansas and to pipe-lines carrying gas to large cities, such as Kansas City, Topeka, Leavenworth, Atchison, St. Joseph, etc. In Oklahoma few factories are yet built and legal conditions are such that no gas has yet been piped out of the state. For these reasons figures for production of natural gas in the two states will show a large preponderance of Kansas over Oklahoma, while the facts

are that there is much more gas developed and shut in in Oklahoma than in Kansas.

In determining the value of gas a number of difficulties are encountered, the chief of which is that it is so nearly impossible to arrive at a satisfactory valuation per unit to put upon the gas. For example, in every town reached by pipe-lines belonging to the Kansas Natural Gas Company the consumer pays a minimum of twenty-five cents per thousand cubic feet of gas consumed for domestic use, and about ten cents for factories, measured at a pressure of about four ounces above normal atmospheric pressure. At least a portion of this same gas is bought by the Kansas Natural Gas Company at something under three cents per thousand cubic feet. What, now, should be the price per thousand for such a consumption? It is evident that the consumer would not do without it even though he had to pay more than twenty-five cents a thousand; and likewise it is true that the Kansas Natural Gas Company has no gas for sale at three cents a thousand.

If we compare the fuel value of gas with coal we have another difficulty in the way, which is hard to overcome, in that we do not know how much gas is equal in value to a ton of coal for consumption. The matter of luxury comes in and makes the use of coal prohibitive for those who can use gas. In the large factories gas is so much more convenient and is so readily used that here again its value is greater than its mere heat-producing capacity, because the labor put upon it in process of consumption is much less than that put upon coal or other fuel.

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In most of our cities, towns and villages where gas is used for domestic purposes it is measured at about four ounces above atmospheric pressure. If, now, the same were measured to them at about fifteen pounds pressure, they would get practically double the amount.

The Pittsburg Meter Company, of East Pittsburg, Pa., has prepared a table showing what multiplier ought to be used for gas measurements above eight ounces in order to bring the

TABLE SHOWING VARIATION IN GAS MEASUREMENTS.

PITTSBURG METER CO. EAST PITTSBURG PA.

MULTIPLIERS TO BE USED FOR GAS AT PRESSURES GREATER THAN EIGHT OUNCES.

LBS.	MULT.	LBS.	MULT.	LBS.	MULT.	LBS.	MULT.	LBS.	MULT.	LBS.	MULT.	LBS.	MULT.
1	1.032	16½	2.032	32	3.032	47½	4.032	63	5.032	78½	6.032	94	7.032
1½	1.064	17	2.064	32½	3.064	48	4.064	63½	5.064	79	6.064	94½	7.064
2	1.097	17½	2.097	33	3.097	48½	4.097	64	5.097	79½	6.097	95	7.097
2½	1.129	18	2.129	33½	3.129	49	4.129	64½	5.129	80	6.129	95½	7.129
3	1.161	18½	2.161	34	3.161	49½	4.161	65	5.161	80½	6.161	96	7.161
3½	1.193	19	2.193	34½	3.193	50	4.193	65½	5.193	81	6.193	96½	7.193
4	1.226	19½	2.226	35	3.226	50½	4.226	66	5.226	81½	6.226	97	7.226
4½	1.258	20	2.258	35½	3.258	51	4.258	66½	5.258	82	6.258	97½	7.258
5	1.290	20½	2.290	36	3.290	51½	4.290	67	5.290	82½	6.290	98	7.290
5½	1.322	21	2.322	36½	3.322	52	4.322	67½	5.322	83	6.322	98½	7.322
6	1.354	21½	2.354	37	3.354	52½	4.354	68	5.354	83½	6.354	99	7.354
6½	1.387	22	2.387	37½	3.387	53	4.387	68½	5.387	84	6.387	99½	7.387
7	1.419	22½	2.419	38	3.419	53½	4.419	69	5.419	84½	6.419	100	7.419
7½	1.452	23	2.452	38½	3.452	54	4.452	69½	5.452	85	6.452	100½	7.452
8	1.484	23½	2.484	39	3.484	54½	4.484	70	5.484	85½	6.484	101	7.484
8½	1.516	24	2.516	39½	3.516	55	4.516	70½	5.516	86	6.516	101½	7.516
9	1.548	24½	2.548	40	3.548	55½	4.548	71	5.548	86½	6.548	102	7.548
9½	1.581	25	2.581	40½	3.581	56	4.581	71½	5.581	87	6.581	102½	7.581
10	1.613	25½	2.613	41	3.613	56½	4.613	72	5.613	87½	6.613	103	7.613
10½	1.645	26	2.645	41½	3.645	57	4.645	72½	5.645	88	6.645	103½	7.645
11	1.677	26½	2.677	42	3.677	57½	4.677	73	5.677	88½	6.677	104	7.677
11½	1.710	27	2.710	42½	3.710	58	4.710	73½	5.710	89	6.710	104½	7.710
12	1.742	27½	2.742	43	3.742	58½	4.742	74	5.742	89½	6.742	105	7.742
12½	1.774	28	2.774	43½	3.774	59	4.774	74½	5.774	90	6.774	105½	7.774
13	1.806	28½	2.806	44	3.806	59½	4.806	75	5.806	90½	6.806	106	7.806
13½	1.839	29	2.839	44½	3.839	60	4.839	75½	5.839	91	6.839	106½	7.839
14	1.871	29½	2.871	45	3.871	60½	4.871	76	5.871	91½	6.871	107	7.871
14½	1.903	30	2.903	45½	3.903	61	4.903	76½	5.903	92	6.903	107½	7.903
15	1.935	30½	2.935	46	3.935	61½	4.935	77	5.935	92½	6.935	108	7.935
15½	1.968	31	2.968	46½	3.968	62	4.968	77½	5.968	93	6.968	108½	7.968
16	2.000	31½	3.000	47	4.000	62½	5.000	78	6.000	93½	7.000	109	8.000

BAROMETER 30.45 INCHES AT SEA LEVEL.
TEMPERATURE 60° FAH.

volume of gas up to what it should be, provided the contract is made for eight-ounce pressure. This table is included herewith and will prove to be one of unusual interest to purchasers of gas. Of course, the difference between four ounces and

eight ounces is not very great, as it is only one-fourth of a pound, or about one-sixtieth of one atmospheric pressure. It will be noted that should the contract call for eight-ounce measurement and the gas actually be measured at one pound above the atmosphere, then the reading should be multiplied by 1.032. If the reading is actually taken when the gas in the pipe has a pressure of ten pounds the reading should be multiplied by 1.613. Should the gas have a pressure of fifteen pounds while passing through the meter the reading should be multiplied by 1.935 in order to get the correct reading of gas under an eight-ounce pressure. And, finally, at the lower right-hand corner of the table it is seen that should the gas in the pipe have a pressure of 109 pounds the reading of the pressure should be multiplied by 8 in order to bring it to the proper measurement.

The above considerations may be surprising to some consumers of gas. At least it will show how much difference there is in the actual amount of fuel present in a thousand cubic feet of gas when measured under different conditions of pressure. A manufacturing company, according to the table, could afford to pay eight times as much per thousand if gas were measured to them under a pressure of 109 pounds in the pipe as it could were it measured to them at a pressure of eight ounces. This is particularly applicable to all considerations of fuel values of natural gas in comparison with coal, oil, wood, etc. It is necessary in all cases to specify the measurement at which gas is to be measured whenever any such calculations are being made.

TABLE SHOWING VALUE OF NATURAL GAS PRODUCED IN KANSAS FROM 1889 TO 1907.

Figures for 1889 to 1896, inclusive, are taken from the reports of the U. S. Geological Survey.

Year.	Value.	Year.	Value.
1889	$15,873	1898	$188,840
1890	12,000	1899	257,500
1891	5,500	1900	602,596
1892	40,795	1901	768,506
1893	50,000	1902	939,375
1894	86,600	1903	1,115 375
1895	112,400	1904	2.891.685
1896	124,750	1905	3,125,250
1897	155,500	1906	3,775.350
		1907	4,250,000
		Total	$28,517,895

The following discussions of the development in the Mid-continental field for the years 1904, 1905, 1906 and 1907 are copied bodily from *The Engineering and Mining Journal,* from which publication they were copied into *The Mineral Industry* for the same years, having been written by the author of this chapter.

OIL AND GAS DEVELOPMENT IN THE MIDCONTINENTAL FIELD DURING 1904.

During 1904 oil development in Kansas and the Indian Territory was unusually vigorous. At the beginning of the year less than 1600 wells were producing oil within the entire area; at the close there were fully 4000. The total production of oil during the year was 5,617,527 barrels, of which Kansas gave 4,250,779 barrels and Indian Territory and Oklahoma the remainder. In 1903 the gross output was 1,071,125 barrels (Kansas, 932,214); and in 1902, 368,849 barrels (Kansas, 331,749). During 1904 the daily average for the whole field rose from 9107 barrels in January to 24,353 barrels in December, averaging 15,287 barrels per day for the year. The average price per barrel was 97 cents in 1904, $1.04 in 1903, and 88¾ cents in 1902.

The most productive areas in Kansas are found principally in Allen, Neosho, Wilson, Montgomery and Chautauqua counties. Early in the year there was great activity in the Bolton field, near Independence, in Montgomery county; also rapid development in all of the other counties named, particularly Chautauqua. By the end of the year activity had moderated to a considerable extent in all parts of Kansas except Chautauqua county.

The new outlying fields that were developed during the year within the state were one in the vicinity of Erie, in Neosho county, and one in the vicinity of Paola, in Miami county, which together gave an output of 14,500 barrels. Some oil developments began about Erie in 1903, but during 1904 a good supply of oil was obtained from many different wells. This has scarcely been marketed at all, on account of a lack of facilities for transportation. Activity about Paola began in earnest in midsummer, 1904, and continued to the end of the year. Here a shallow oil-sand is found at a depth of about 350 feet, which seems to be as productive as the average oil-sand of Humboldt and Chanute. The Standard Oil Company has promised Paola a pipe-line.

Oil development at Coffeyville began during 1903 and continued throughout 1904. A fair amount of good oil was found in shallow sands from 350 to 500 feet deep. This territory seems to be very spotted; so much so that during the latter part of the year prospecting was not crowded. Oil was found also about Tyro, nine miles east of Caney, near the southern boundary of the state. That field, likewise, is spotted, some wells flowing as much as 250 barrels per day, while others near by may be dry. A fair pool was opened up during the year in the vicinity of Wayside, on the Santa Fe railway, about six miles southwest of Bolton, or twelve miles from Independence.

In Chautauqua county there seem to be three well-defined pools—the Spurlock-Blundell pool, near the southern line of the county, south and a little west of Peru; the Hoffman pool, from three to five miles south of Sedan, and the pool immediately under the little town of Peru. The Spurlock-Blundell area had the greater development early in the year, but later the Hoffman field became the most active. It bids fair to develop into the best oil-field yet opened up in the state. More than a hundred wells were put down on town lots in Peru. They started with a capacity of from twenty to thirty barrels per day, but are now almost exhausted. In the vicinity of Humboldt and Chanute, oil is obtained at from 700 to 900 feet; in the Bolton-Wayside area from 800 to 1000 feet; at Coffeyville oil thus far found is shallow, from 350 to 500 feet; at Tyro it is from 1050 to 1200 feet; at Caney, near 1400 feet. In the Spurlock-Blundell pool oil is usually found at 1100 to 1150 feet, and in the Hoffman pool at about 1200 to 1300 feet depth. The oil-bearing rock is the Cherokee shale, the lowermost member of the Pennsylvania series, resting unconformably upon the Boone formation, which, in adjacent parts of Missouri and Arkansas, is noted for its zinc and lead ores. No gas or oil has been found in Kansas in or below the Boone horizon.

Throughout more than half the year development in the Indian Territory was confined principally to the lands belonging to the Osage Indians, on account of difficulties in the way of obtaining leases elsewhere. The Indian Territory Illuminating Oil Company has a blanket lease on the entire Osage lands and subleases to actual operators. Development was confined principally to the extreme eastern portion of the Osage lands until near the close of the year. In September a good oil-well was brought in at Cleveland, in Oklahoma Territory, just across

the Arkansas river from the Osage lands. This resulted in a great rush to all adjacent lands, both in Cleveland on the south and in the Osage Nation on the north, and at present many drills are in operation on both sides of the river. It is reported that leases there are higher than anywhere else, excepting immediately adjacent to Bartlesville. Development was also carried on throughout the year in the vicinity of Muskogee, Chelsea, Tulsa, Red Fork and Bartlesville.

Later in the year the Secretary of the Interior began to confirm leases within the Cherokee territory, and drilling began immediately with great activity, so that at present derricks are being erected and drills are in operation in many places. A few small areas were leased previously, notably section 12, including nearly all the town site of Bartlesville, which was leased to the Cudahy company; and an area of twelve sections near Chelsea leased to the Cherokee Oil and Gas Company. A part of the town site of Bartlesville was deeded outright, so that the owners can lease or drill at their pleasure. Since Cherokee leases have been confirmed drilling has become very active in the vicinity of the little town of Alluwe, about thirty miles south of Coffeyville, and also at the villages of Dewey and Lenapah, the former being four miles north of Bartlesville and the latter ten miles south of Coffeyville. At the close of November Chelsea had about 96 producing wells, Red Fork 50, Cleveland 10, Muskogee 35 or more, Bartlesville nearly 200, and other points within the Osage territory 75 or 80 more.

At Chelsea and Alluwe the wells are from 300 to 600 feet in depth; at Red Fork and Tulsa from 700 to 1000 feet; at Muskogee 1000 to 1200 feet; at Bartlesville about 1100 to 1400, and at Cleveland 1600 to 1700 feet, the deepest of any in the entire Kansas-Indian Territory field.

Some recent analyses of Kansas oils are given in the table (page 208). The method consisted of distilling the volatile products in fractions, each approximating one-tenth of the original volume, while noting the limiting temperatures in Centigrade and the specific gravity of each fraction in Baumé degrees.

The Standard Oil Company, under the title Forest Oil Company, but later changed to Prairie Oil and Gas Company, entered the field in 1895; in 1897 it built a 500-barrel refinery at Neodesha. Within the last two years it has built a refinery at Kansas City, Mo., with a pipe system branching into Kansas

DISTILLATION OF KANSAS PETROLEUMS.[108]

	Humboldt.		Neodesha.		Neodesha, 2.	
	Temp. Deg. C.	Sp. gr. Deg. B.	Temp. Deg. C.	Sp. gr. Deg. B.	Temp. Deg. C.	Sp. gr. Deg. B.
Crude, at 60° F	.....	27.3	.....	32.8	.....	31.5
First tenth	95–160	40.1	95–201	52.1	95–200	.....
Second tenth	160–190	40.1	201–298	38.8	200–285	.....
Third tenth	190–250	32.5	298–320	33.9	285–320	.....
Fourth tenth	250–265	32.5	320–337	30.4	320–330	.....
Fifth tenth	265–270	31.5	337–350	29.5	330–345	.....
Sixth tenth	270–278	31.5	350–...	29.0	345–360	.....
Seventh tenth	278–305	30.5	.....	27.9	.....	.....
Eighth tenth	305–340	30.5	.....	27.8	.....	.....
Ninth tenth	340–360	.....	.....	27.0	.....	.....
Tenth tenth	.....	.....	.....	26.9	.....	.....
Coke, per cent. by weight	3.20	.....	0.98	.....	0.77	.....

and Indian Territory, and reaching every producer of reasonable magnitude. The prices paid at the wells for oil to be transported by the pipe-line ranged from 31 cents for the heavy oils (22°-28° B.) to 72 cents for the lighter (32° B.) oils. This stimulated a production greater than the refiners could handle, so that, with the successive reductions in prices, many producers failed to pay dividends. Resentment against the trust finally became so acute that, in the winter of 1904, the legislature was led to appropriate $410,000 to build an independent state refinery at Peru, seeking to avoid the constitutional prohibition of state participation in "works of internal improvement" by making the refinery an adjunct of the State Penitentiary. The supreme court has since ruled the act unconstitutional. The federal commissioner of the Bureau of Corporations, however, is investigating the whole matter.

OIL AND GAS DEVELOPMENT IN MIDCONTINENTAL FIELD IN 1905.

Geography and Development.—The term "Midcontinental field" applies to the oil-and-gas fields of Kansas, Indian Territory and Oklahoma. The area may be defined approximately as follows: From Kansas City draw a line westward to Lawrence, Kan., a distance of about forty miles; thence south and west, by way of Ottawa, Moody, Toronto and Sedan, to the south line of Kansas; continue in the same general direction to Cimarron river in the Indian Territory; from there extend the line nearly southeast by way of Sapulpa to Muskogee, and thence in a general northeasterly direction by way of Chelsea, Vinita and Oswego back to Kansas City.

Outside of this area a number of outlying discoveries have

108. Proceedings of the Western Gas Association, Chicago, May 17, 1905; in the *Progressive Age*, August 1, 1905, p. 396.

been made; such as gas at Arkansas City and Newkirk, and oil and gas near Ardmore, in the Chickasaw territory. The Arkansas City-Newkirk field is evidently about the same geologically as the large field, but the exact geological conditions about Ardmore (and a few other places where traces of oil and gas have been found) have not yet been thoroughly worked out.

Development during 1905 extended the fields by only a small area. More gas was found at Arkansas City than was thought to exist. The heavy developments about Pawhuska, in the Osage territory, and in the oil-fields of Cleveland, Okla., and the shallow oil about Alluwe and Coody's Bluff, were the principal additions for the year, although small developments were made in all these places at an early date.

In Kansas the only developments of note were in the vicinity of Paola and Rantoul. A somewhat unexpected development of shallow oil was made about Paola; it was unexpected because much drilling for gas had been done previously without uncovering oil-pools. Rantoul is a little village on the Missouri Pacific railroad between Osawatomie and Ottawa. Early in the year a number of wells were drilled there, which, almost without exception, produced either oil or gas in paying quantities. At present, a nice little field of shallow sand is developed, producing fair quantities of both oil and gas. This seems to be a southwest trend of the Paola-Osawatomie field. The pay sand lies at varying depths, from 350 to 600 feet or more.

Alluwe, in the Cherokee Nation, is a little village which until a few months ago consisted of some half a dozen houses, including a little country store, or trading-post. This was the former home of the Delaware chief Little Foot, and the present home of his son-in-law, Mr. Campbell, who now has a princely income from royalties on oil leases. Two or three years ago two prospect wells were put down, ostensibly for water. Each of them struck oil-sand at about 500 feet, and the wells stood full of oil for two years or more. When leasing in the Cherokee Nation began in earnest a year and a half ago, information about these wells leaked out and leases in that vicinity soon came to a premium. The old lease of the Cherokee Illuminating Oil Company, covering twelve square miles, lies six miles south of Alluwe. Development has proved a north-and-south trend, reaching all the way from the old lease (or "big lease," as it is generally called) to Coody's Bluff, ten miles north of Alluwe,

forming a north-and-south trend known to be from fifteen to eighteen miles long. Here oil of good quality is found at depths varying from 300 to 650 feet. In daily capacity the wells range from 10 to 500 barrels. Most of them flow from one to six weeks without pumping. This is the most important shallow-sand territory yet developed in the entire Midcontinental area.

At Cleveland the oil-sand is very deep (around 1900 feet), with slight variations in different wells. The production ranges from 25 to 300 barrels per well initial capacity, making this an important oil-pool.

Another new pool opened entirely in 1905 is located to the north and west of Dewey, four miles north of Bartlesville. The first development here was made by Stubbs & Low, early in the year, on a lease lying one and a half miles northwest of town. The oil-sand averages 1400 feet below the surface; although a shallower sand, about 800 feet down, is a small producer in some of the wells. From this original development, in almost all directions, new wells are frequently brought in. Early in November a well two or three miles southeast of Dewey started flowing at the rate of 1000 barrels per day; at the end of a week it had settled to 450 barrels. A few good producers have been brought in still further northeast toward the Kansas line; but up to the close of the year there was left an unexplored zone nearly ten miles wide between the developed area and the southern Kansas line, with good reasons for believing it may become as productive as any area yet developed.

The most extensive development throughout the year was in the areas fairly well proven during 1904. From the vicinity of Bartlesville southward, along the extreme eastern line of the Osage territory, a surprisingly large number of strong wells were brought in. A number of them have begun flowing at the rate of 1000 barrels per day, and have held weeks before dropping to 500 barrels. For matters of convenience, holders of the blanket lease on the Osage lands divided the eastern area into three north-and-south columns, approximately three miles wide per column. East-and-west lines were now drawn half a mile apart; each subarea is called a "lot," and is numbered from the state line southward to the south side of the territory, a distance of fifty-eight miles, making 116 lots in each tier. Practically all the land extending from Bartlesville to lot 70

or 75 is proved territory, with richer areas in certain places. Lots 44 and 45 are excellent, with another rich pool about lots 51 and 52; the richest of all is in the vicinity of lots 61 to 67. Here it seems almost impossible to find a dry well; numerous wells had initial capacities above 300 barrels per day. West from this immediate area, on the middle tier of lots (that is, lots 169 to 172), there is also a productive area; and still west on the third tier (that is, lots 293 to 296), and in parts of township 24, range 10, still farther west, excellent oil-pools have been developed. It seems probable that here is an east-and-west trend reaching from the east side of the Osage leases westward a distance of fifteen miles. The north-and-south development from Bartlesville to lot 68 is another stretch of excellent land, eighteen miles long. East of the territory line, and within the Cherokee land in the vicinity of Ramona, a number of dry wells have been drilled, implying a limitation of the field on the east side.

Outside of the richest areas already described, other excellent pools have been developed in part. Thus, a zone reaches west and a little north from Bartlesville over into range 10, which is dotted here and there all over with good wells. To the southwest, across the river north from Cleveland, a number of good wells are found; again, in the vicinity of Pawhuska, both oil-wells and gas-wells are found, which implies a profitable area. The development in different parts of the Indian Territory has been greater than to the north in the state of Kansas, due in part to better wells and in part to legal considerations to be explained later.

In Kansas, development was not great during 1905. The Chanute-Humboldt pool, the Bolton pool, the Coffeyville pool, the Tyro pool and the Caney pool were tolerably well defined before the close of 1904; then a severe winter came on, and just at the beginning of milder weather the price of oil dropped so low that producers had no incentive to drill. In fact, for about six months (from February to July, inclusive) it was impossible to market more than a small fraction of oil which might have been produced from the wells drilled. As a result, surprisingly few wells were drilled in Kansas. Chautauqua county witnessed more drilling than any other part of the state outside of Paola and Rantoul, already mentioned; partly because the grade of oil was highest here and commanded the highest market price; and further, on account of less uncer-

tainty in drilling. Three miles straight south from Sedan, the county-seat, is a pool known as the Hoffman pool. Oil is obtained there at from 1050 to 1250 feet; the wells range from 20 to 256 barrels initial capacity, many of them making 75 barrels after months of pumping. Two miles to the east, and from two to six miles south of the Hoffman field, is an area trending north and south, about two miles wide and reaching down to the state line, commonly known as the Blundell-Spurlock area. This was the first developed in Chautauqua county outside the immediate environs of Peru; on the whole it has proved to be a rich field. Immediately south of Peru about three miles is another pool, developed during 1905, known as the Scott pool. There are nearly forty wells along a north-and-south line about two miles long, with dry wells on the east and light gas-wells on the west. There seems to be a north-and-south trend of gas territory between this and the Blundell-Spurlock pool.

Production.—The production for the year 1905 was about twelve million barrels. The table given on a subsequent page shows the total production by months of the entire area, as bought by the Prairie Oil and Gas Company and according to its monthly report; it exhibits the total runs, daily average of the same; total deliveries to refineries, daily average of same; total put into tanks, daily average of same; and, finally, total stocks on hand at the end of the year and for each month during the year.

To these should be added a small amount consumed by the independent refineries at Humboldt, Paola, Cherryvale, etc., and the still smaller amount used as fuel- and lubricating-oils, which may be estimated at from 100,000 to 125,000 barrels.

It will be noticed that, beginning with July, the monthly runs exceeded one million barrels; and that for the last three months it exceeded one and one-third million; so that 1905 turns over the industry to the new year on a basis of more than sixteen million barrels annual production. Of this amount, much more than one-half came from the Indian Territory; but at the present an exact division cannot be made. Presumably, however, not more than one-third of it came from Kansas.

The extra development in the Indian Territory, as already explained, was due in part to stronger wells and less uncertainty in drilling. But another very important factor is the legal status of leases on Indian lands. The Secretary of the In-

terior requires a certain form of lease, one clause in which specifies that at least one well shall be drilled by the end of the first twelve months after the lease is approved. This has been the most important factor in forcing drilling. The secretary is of the opinion that he is best serving the cause of the Indian by giving him royalties from oil-wells as rapidly as possible. It is generally believed that the low price of oil is due to the great excess of development over consumption. According to the table given, the Prairie Oil Company has fourteen million barrels of oil stocks stored here and there throughout the oil-producing territory and at the Sugar Creek refinery near Kansas City, with an increase of nearly 40,000 barrels per day. With the entire area controlled by one good business head, development would be stopped until the stocks had decreased greatly and the price of oil advanced; but with the Secretary of the Interior insisting on the "development clause," no one cares to jeopardize the title of valuable leases by declining to drill; therefore the price goes downward, and production continues to increase.

MONTHLY PIPE-LINE RUNS OF THE PRAIRIE OIL AND GAS COMPANY, 1905.
(IN BARRELS.)

MONTH.	Runs.	Daily average.	Deliveries.	Daily average	Put into tanks.	Daily average.	Total stocks.
January	793,648	25,602	315,426	10,175	478,222	15,427	5,655,672
February	564,482	20,160	292,649	10,452	271,833	9,708	5,912,207
March	695,908	22,449	249,564	8,050	308,087	9,938	6,327,923
April	549,338	18,311	241,252	8,042	308,087	10,270	6,657,926
May	784,229	25,298	219,065	7,067	563,164	18,231	7,256,628
June	715,397	23,847	185,889	6,196	529,508	17,650	7,573,536
July	1,091,000	35,194	206,155	6,650	884,844	28,543	8,265,004
August	1,212,912	39,126	279,391	9,013	933,521	30,114	9,213,216
September	1,208,362	40,112	318,864	10,629	884,498	29,483	10,618,676
October	1,380,208	44,522	209,094	6,745	1,171,114	37,778	11,585,178
November	1,355,012	45,167	416,476	13,883	938,535	31,285	12,510,152
December	1,509,325	48,688	684,642	22,085	824,683	26,603	13,250,118
Totals	11,854,821	32,373	3,618,467	9,916	8,096,096	22,086	.....

Gas.—The production of gas was greatly increased during 1905. Early in the year the Kansas Natural Gas Company began buying property, and has continued that policy to the present. It now owns all the leases formerly owned by almost every big gas company in the state, and stands ready at all times to pay for any new developments that may be made. It now owns nearly all the good production of Montgomery and Wilson counties, the two richest gas-fields in the Midcontinental area. From near Independence south to the state line, wells with a daily capacity of fifteen million cubic feet are compara-

tively common, and some producing thirty million are known. One well measured when open (by using the Pitot tube, the mouth of which was placed a little to one side of the center of an 8¼-inch pipe) gave a pressure of thirty-eight pounds on the gage attached; this is perhaps the largest well in the entire region.

A well drilled during October near the state line tested close to thirty-five million cubic feet. In the Indian Territory some enormous gas-wells likewise have been found, a number of which range from fifteen to twenty million cubic feet. The strongest wells are near the line between the Osage and Cherokee lands, some on one side and some on the other. In the vicinity of Bartlesville gas is found in the sand above the principal oil-sand. Frequently this gas is allowed to escape and the drill sent on down to the oil. In other places gas is in a sandstone corresponding to the oil-sand. Recently a number of strong gas-wells have been drilled two or three miles southeast of Bartlesville. Some of the strongest wells are found west of Ramona; in the vicinity of Pawhuska wells ranging from eight to fifteen million cubic feet have been obtained.

The Kansas Natural Gas Company now has its pipe-lines laid northward beyond the Kansas river almost to Atchison and St. Joseph, with one branch leading west to Topeka and another line to Kansas City. A large pumping-station is established at the little town of Petrolia, on the west side of the Neosho river, about midway between Humboldt and Chanute. Pipes from all over the gas-field to the south converge at this point. Two sixteen-inch pipes are laid, side by side, from the pumping-station to Ottawa. Here they diverge, one going to Kansas City, the other north to Lawrence, Leavenworth and Atchison. About three miles south of Lawrence a side line is carried westward to Topeka.

Gas is sold throughout these northern towns at twenty-five cents per thousand for domestic consumption, measured at about eight ounces above atmospheric pressure. For manufacturing purposes it is offered at lower figures; but up to the present few factories have adopted its use, as gas cannot compete with coal for manufacturing purposes unless sold considerably below any figures yet offered. All the important gas towns in Kansas and Indian Territory are still offering three-cent gas to manufacturers; some of them in the Indian Territory are offering it at a lower price.

Refineries and Pipe-lines.—The Standard Oil Company has a small refinery at Neodesha, with a capacity of about 3500 barrels crude per day, which was kept in operation throughout the year at its full capacity. It has built a larger refinery at Sugar Creek, in the eastern suburbs of Kansas City, with a reported capacity of 6000 barrels per day, and which began receiving oil early in the year. One eight-inch pipe-line leads to the Sugar Creek refinery from Neodesha, with many laterals ramifying through the entire oil-field to the south. At present, a second eight-inch pipe-line is building to Sugar Creek. Also, an eight-inch line reaches from Sugar Creek to Whiting, Ind., which was open for operation during the latter part of the year.

Large tank-farms have been established at different places throughout the field and at each refinery, the largest one at present being at Neodesha, with smaller ones at Humboldt, Caney, Bartlesville, Cleveland, Ramona, and perhaps other places. Tanks are still building at a rapid rate in order to keep ahead of production.

A number of small independent refineries are located in the state, one at each of the following places: Humboldt, Paola, Cherryvale, Niotaze and Longton. Those at Humboldt and Paola have been in operation the greater part of the year, consuming an aggregate of about 300 barrels per day. The others have not yet done much refining and are small.

Markets.—Until early in the year 1905 the Prairie Oil and Gas Company made a somewhat arbitrary division of the Kansas oil-field for the purpose of establishing prices. In all market quotations previous to this time Kansas oil was graded as South Neodesha and North Neodesha, with the former bringing regularly 20 cents a barrel more than the latter. The highest price paid in the field was $1.38 for South Neodesha oil early in the year 1904. This quotation lasted but a few days, when the price began to drop and gradually declined throughout the year, reaching 72 cents in December. The downward tendency continued until it reached the low price of 50 cents a barrel for the best Kansas-Indian Territory oil during the first half of 1905, at which point the market rested for months. In the middle autumn a 2-cent advance was made, after which the market was stationary to the end of the year.

Early in the year the old-fashioned way of grading oil into South Neodesha and North Neodesha was abandoned, and a

gravity scale was adopted. Under this regulation, oil testing 32° B., or more, was given the top price, and a decrease of ten cents per barrel for each degree, or five cents for each half-degree, was put upon the lower grades of oil. Gravity tests were made by the gager and were strictly enforced, often a shade of one-tenth degree causing a difference of five cents per barrel.

A portion of the oil from Montgomery county, all of the oil from Chautauqua county in Kansas, and practically all from the Indian Territory-Oklahoma field, tests 32° B. or more, some of it reaching as high as 37° B. or 38° B. Almost all the remaining Kansas oil tests below 32° B. Although a penalty of five cents for each half-degree was imposed on oil below 32° B., yet a corresponding increase was not made for that above 32° B., so that wells producing oil testing from 35° B. to 38° B. have never been more profitable than they would have been had their product been barely above 32° B.

Future Developments.—The success attending present operations in the Indian Territory is so great that future development will probably increase over the present production. Should the price of oil start upward with a fair promise of reaching one dollar per barrel, almost every leaseholder in the oil region would begin drilling. Under such circumstances it is difficult to tell what the result would be. Could we have another year of such prices, with a demand for the entire production, it would not be surprising if the field should reach a capacity anywhere from 75,000 to 100,000 barrels per day.

OIL AND GAS IN THE MIDCONTINENTAL FIELD, 1906.

The production of oil and gas in the Midcontinental field was much greater in 1906 than in any previous year. The oil was bought principally by the Prairie Oil and Gas Company, the Standard Oil Company in Kansas. At present there are nine independent refineries in Kansas and one in Indian Territory, but their consumption was small, due in part to their small size and in part to the fact that several of them did not begin operation until late in the year. A considerable amount of oil was used for fuel and was shipped to many places here and there over the state. One producer, C. A. Stannard, operated a system of tank-cars and supplied customers in western and central Kansas with a comparatively large amount of crude oil.

TABLE SHOWING MONTHLY PIPE-LINE RUNS OF THE PRAIRIE OIL AND GAS COMPANY, 1906, MIDCONTINENTAL FIELD. (IN BARRELS.)

MONTH.	Total run.	Daily average.	Deliveries.	Stored.
January	1,472,214	47,491	539,009	933,205
February	1,352,531	43,305	527,995	824,536
March	1,693,182	54,619	719,320	973,862
April	1,779,251	59,308	752,625	1,026,626
May	1,741,941	56,192	802,838	939,103
June	1,688,433	56,281	642,128	1,046,304
July	2,022,215	65,233	648,439	1,353,776
August	1,779,262	57,396	900,755	878,508
September	1,546,719	51,557	846,128	700,591
October	2,009,650	64,827	1,559,520	450,130
November	1,945,195	64,839	1,680,928	264,267
December	1,920,562	64,019	1,528,524	392,038

The total of the deliveries in 1906 was 11,168,209 barrels. The total runs were 20,951,155 barrels (average of 690,067 per month), to which is to be added 973,750 barrels for other sales, giving a total production of 21,924,905 barrels in the Midcontinental field. No available method is at hand at present to determine definitely what portion of the above grand total given came from Kansas and what portion from Oklahoma. It is probable, however, that about one-fourth of the entire amount came from Kansas and three-fourths from Oklahoma.

Developments.—During 1906 the only new development of any considerable note was in the Glenn pool area, a few miles southeast of Red Fork. Here a wonderful pool of oil was discovered, which already furnishes many wells producing more than 1000 barrels a day. Apparently the boundary of the pool has not yet been located, as new wells occasionally are found almost on all sides of it.

The next most remarkable discovery was in section 27, east and a little south of Dewey, four miles northeast of Bartlesville. Here is an area nearly one mile across which was wonderfully productive in which also a few 1000-barrel wells were brought in. Drilling was so active, however, that they soon had the boundaries of the pool located and the wells have now run down to 200 to 300 barrels daily capacity.

A large amount of development was carried on during the entire year with an aggregate of close to 2000 wells drilled. During the first half of the year development was very active in the shallow pool around Alluwe and a very large production was obtained, some wells reaching 400 to 500 barrels capacity. The next greatest production was in the Osage near the eastern boundary, south of Bartlesville. Next to the Glenn pool this

area remains the most remarkable in the Midcontinental field. It seems that we have here a long, slender north-and-south pool lying parallel with the ninety-sixth meridian, which is the boundary between the Cherokee and the Osage lands, lying principally in the Osage, with a few good wells east of the boundary-line and a few from five to ten miles to the west. In a north-and-south direction the pool extends nearly to Tulsa, with only occasional dry wells interspersed. A number of these wells started at 1000 barrels per day, and they held up their capacity as well, or better, than any other wells in the area. Farther west in the Osage drilling has been done irregularly with quite indifferent success. Some wells are good oil-wells, others good gas-wells, and quite a number of them dry.

But little drilling was done in Kansas during 1906. Early in the year there was some development in the vicinity of Paola, Osawatomie and Rantoul; also a small amount in the Hoffman field, Chautauqua county, five miles west of Peru, and an occasional well elsewhere here and there over the entire Kansas territory. But in general all the drilling done in Kansas was in searching for gas, as will be explained later.

Markets.—The Prairie Oil and Gas Company is the principal purchaser of oil, and, therefore, fixes the price. The lesser concerns consume but little, and, although occasionally they bid a little above the market price, they have little, if any, influence on the market. In fact, some of them can hardly obtain as large a quantity as they desire. There is a sentiment abroad that if a producer once sells to an independent concern the Prairie Oil and Gas Company will not take his supply or any fraction of it. It is probable this has not been put to a test, but the wide-spread belief that such would be the case has kept a number of people selling to the Prairie and declining bids from others.

At the beginning of the year the price paid was fifty-two cents per barrel for oil with a specific gravity of 32° B. or lighter. During the summer this price gradually dropped until the low mark of thirty-nine cents was reached in August, at which point it has remained. For oils heavier than 32° B., in most cases, a reduction of five cents was made for each half degree.

Gas.—The Midcontinental field has witnessed the most activity in developing and marketing gas. The Kansas Natural Gas Company got its pipe-line laid to Kansas City, Kan., To-

peka, Lawrence and Leavenworth before the close of 1905, and by February the pipes were in Atchison and St. Joseph, Mo. Certain difficulties regarding a franchise kept it out of Kansas City, Mo., until the autumn of 1906. By the close of 1905 also a pipe-line had extended eastward from the gas-fields to Joplin and Carthage, in Missouri, with laterals ramifying the entire Joplin mining region. During the summer of 1906 a pipe-line was carried westward from the gas-fields toward Wichita and Hutchinson and has just now reached the former city. All of these mains have laterals from which they supply the various towns and villages along their lines.

To supply such large quantities of natural gas for domestic consumption it is necessary to have a large amount developed in the gas-fields. On this account drilling was fairly active in many different parts of the gas-fields of Kansas. The pipe-line reaching northward to Kansas City, etc., is supplied principally from the vicinities of Iola, Humboldt, Chanute, Neodesha and intervening locations; that eastward to the Joplin area is supplied from the Montgomery county fields in the vicinity of Independence and Coffeyville, and the supply for the western pipe-line will come principally from western Montgomery, Chautauqua and other counties in Kansas, and probably from the Cherokee and Osagè country, although that matter is not definitely settled. It is reported that a prominent gas producer applied to the Secretary of the Interior for permission to pipe gas out of Indian Territory and was denied the privilege. There seems to be no law, however, to prevent such an undertaking.

During 1906 the most extensive developments of gas were in Montgomery county, Kansas, south of Independence, and in the Cherokee Nation throughout a strip from five to ten miles wide, reaching from the south side of Kansas southward almost to the Arkansas river. In fact, gas has been developed in Indian Territory to such an enormous extent in connection with oil development that the Cherokee and Osage territories probably could supply two or three times as much gas as is developed in Kansas. A great deal of this Territory gas is shut in awaiting a market, while other portions are piped to various towns and villages and retailed for domestic consumption. Practically no large manufacturing concerns are established south of the state line. This is due principally to the chaotic condition of land titles in Indian Territory. Different laws of

Congress and different rulings of the Interior Department have matters in such a shape that to the ordinary mind they are very confusing, and, as a result, capitalists prefer to remain away rather than jeopardize their holdings by insecure titles.

In Kansas, however, factories are on the increase so rapidly that the best judges are becoming alarmed lest the gas should become entirely exhausted. A number of zinc smelters in the state have enlarged their capacity and Portland cement plants have increased in number and in size. Five such plants are now in operation, consuming from forty to fifty million cubic feet of gas per day, and two or three others are in contemplation.

Gas-wells near the southern end of Kansas and those in the Cherokee Nation generally are very large. A well from ten to fifteen million cubic feet per day is nothing unusual and some of them run up to thirty or forty million. The somewhat famous well in the Cherokee Nation which caught fire in the spring of 1906 and burned for several weeks was estimated at thirty million cubic feet before the gas was ignited, and before it was completely closed it was estimated at sixty million cubic feet capacity, although no accurate measurements were made. In the outlying borders, however, wells average much less, and some of them are even less than one million cubic feet.

Gas Markets.—The price of gas for domestic consumption along all of the long pipe-lines is twenty-five cents per 1000 cubic feet, meter rates. The Kansas Natural Gas Company is offering gas to large factories at ten cents a thousand, but this is generally considered higher than coal, and as a result but little coal has been driven out of the factories. In the gas-fields a number of the towns and cities still pay the same flat rates they did years ago—that is, from ten to fifteen cents each for lights per month and from one dollar to two dollars each for stoves. Also, a number of the factories, such as the glass factory at Coffeyville, the brick-kilns at Coffeyville, Independence, Sycamore, etc., get gas at the old rates of three cents per thousand. But no new contracts on this basis are sought for by the gas companies. Occasionally parties owning gas will make such contracts for factories or for large consumers. It must be said, however, that all indications are that the day of cheap gas for large factories in this territory is almost past.

OIL AND GAS IN THE MIDCONTINENTAL FIELD, 1907.

During the year 1907 a very large development was produced in the Midcontinental field. The oil development was confined almost entirely to the Indian Territory, now Oklahoma, but a large supply of gas was developed in Kansas. Likewise the total oil production in the Midcontinental field was produced very largely by Oklahoma. It is impractical to quote figures for each state, as the statistics obtainable are gathered in such a way that no discrimination is made.

Oil.—The Prairie Oil and Gas Company (Standard) was the principal consumer of oil, although other interests, such as independent pipe-line companies, independent refineries and dealers in fuel-oil consumed a comparatively large amount. The accompanying table gives a summary of the monthly reports of the Prairie Oil and Gas Company, showing a total of 35,756,366.76 barrels handled by this company. Much the greater part of this was used for refining purposes, so that only 10,762,333.34 barrels were stored. This brings the total storage of the Prairie Oil and Gas Company at the close of 1907 up to the large sum of 33,703,367.74 barrels. To obtain the total production of the Midcontinental field, we must add to these figures the consumption by the independent refineries, the consumption as fuel-oil, and runs by the independent pipe-line companies.

Nine independent refineries were in operation during the year. The one at Paola was bought by the Standard Oil Company during the year; a few other smaller ones were operated irregularly, and these, when in full operation, had a capacity of only a few hundred barrels per day. The largest refineries are at Humboldt and Chanute. A conservative estimate of the total consumption of the independent refineries plus the total crude oil used for fuel is 2,309,500 barrels.

The Gulf Pipe-line Company completed a line from the Glenn pool to the Gulf of Mexico and began pumping oil about October 1. This company began storing oil in January. Before the pipe-line was built it shipped largely by rail, and even yet ships small quantities by rail from wells not yet connected with the pipe-line. A fair estimate of the business done by this company during the year is 5,381,794 barrels, the output during the last half of December only being estimated. The Texas company also is shipping large quantities of oil from the Midcontinental field. It began shipping by rail in March; by Octo-

ber the company had completed its pipe-line as far south as Dallas and hopes that it will reach tide-water by the end of the year. The Texas company handled a total of 3,359,265 barrels.

The Haywood Company, of Texas, also is shipping extensively by rail, supplying fuel-oil to various parts of Texas. It is not known definitely how much this company has produced, but presumably about 750,000 barrels. These, added to the figures for the Prairie Oil and Gas Company given above, make a total of 47,556,905.76 barrels.

TABLE SHOWING MONTHLY PIPE-LINE RUNS BY PRAIRIE OIL AND GAS COMPANY, 1907, MIDCONTINENTAL FIELD.

MONTH.	Total runs, barrels.	Daily average, barrels.	Deliveries, barrels.	Stored, barrels.
January	2,337,164 90	75,392.42	1,646,090.76	691,074.14
February	2,292,116.70	81,861.31	1,759,151.91	532,964.79
March	2,795,969.12	90,192.55	1,965,586.57	830,382.55
April	3,098,915.89	103,297.20	2,166,236.16	932,679.73
May	3,023,776.68	97,541.18	2,342,348.78	681,427.90
June	3,021,285.46	100,709.52	2,162,624.65	858,660.81
July	3,063,284.85	98,493.06	2,325,471.93	727,812.92
August	3,213,547.84	103,662 83	2,281,436.97	932,110.67
September	3,089,627.93	102,987.60	2,200,032.11	889,595.82
October	3,486,804.13	112,477.55	2,267,631.40	1,219,172.73
November	3,231,769.51	107,725.65	1,942,309.80	1,289,459.71
December	3,112,103.95	100,390.45	1,872,689.40	1,176,991.57
Totals	35,756,366.76		24,931,610.44	10,762,333.34

OIL PRODUCTION, MIDCONTINENTAL FIELD, 1907.

Prairie Oil and Gas Company	35,756,366.76	barrels.
Independent refineries and fuel	2,309,500.00	"
The Gulf Pipe-line Company	5,381,794.00	"
The Texas Company	3,359,245.00	"
The Haywood Company	750,000.00	"
Total	47,556,905.76	barrels

Oil Developments.—The most remarkable developments during 1907 were in the Glenn pool, located about ten miles south of Tulsa, Okla. Here a number of wells with an initial capacity close to 2000 barrels per day have been developed, and also many others producing more than 1000 barrels per day. The Glenn, therefore, is the most remarkable pool yet developed in the Midcontinental field. How long it will continue to be so productive, of course, no one can tell, but it is certainly one of the greatest oil-fields ever developed in America.

About the middle of the year considerable excitement was caused by finding oil near the new town of Morris, thirty miles south from the Glenn pool toward Ardmore; a few good wells were obtained, but not much drilling had been done before a number of dry wells were obtained, a fact which checked development.

A nice field has been developed along Hogshooter creek, from six to fifteen miles southeast of Bartlesville. Late in 1906 a well was drilled and plugged; then a report was given out that the well was abandoned. But the company that drilled the well soon began to acquire other leases; the suspicion of others was aroused, and a miniature boom resulted. In a short time a number of different companies were drilling on different leases and a nice group of oil-wells and gas-wells were developed; the larger of the oil-wells have a capacity of about 500 barrels of oil per day and the gas-wells from five to fifteen million cubic feet of gas.

During the first half of December what appears to be a possible repetition of the Glenn pool was developed in the northeast part of the Osage reservation, only a few miles west of Dewey, the largest well being on lot 32. Previously the Dewey-Copan field was limited on the west by a number of dry wells. These checked developments in a westward direction, but some one finally grew bold enough to go a few miles farther west, with the results described. It is reported that one well has been obtained equal to if not greater than the biggest well of the Glenn pool.

The districts productive at the close of 1906 remained equally productive during 1907. The shallow field in the Alluwe-Chelsea district has sustained its production, although but few wells have been brought in, especially since the middle of the year. This is also true with reference to the Dewey field, the Bartlesville field, and practically all the others. A good, healthy activity prevails, but developments have been confined principally to pools already opened up.

A number of different rulings were given out by the Secretary of the Interior, some of which stimulated development, but the greater number had the opposite effect. During October a series of rulings were made regarding oil royalties, gas royalties, and the transfer of leases. These rulings were so objectionable to operators that development work was practically stopped. The royalties in many instances were increased and in some other ways restrictions were enforced which were very objectionable to the operators.

Natural Gas in Kansas.—Every year it becomes more difficult to estimate the value of gas produced in Kansas. At the present time pipe-line companies are paying as high as three cents per 1000 cubic feet for gas delivered to them directly

from the wells. A number of private producers are disposing of their gas in this way. Other producers have contracts at a less price. Kansas now has more than 125 towns and cities using natural gas. A great majority of these use meters and pay at the rate of twenty-five cents per 1000 cubic feet, some even thirty cents. The Kansas Natural Gas Company is the largest retail dealer, but by no means the only one. The pipe-line of this company goes as far north as St. Joseph, Mo., taking in the larger cities of St. Joseph, Atchison, Leavenworth, Lawrence, and Topeka, and also the smaller cities and towns between. A pipe-line also reaches Kansas City, which has an aggregate population of nearly 400,000, about two-thirds of whom are now using natural gas. Another pipe-line belonging to the Kansas Natural Gas Company is carried east from the gas-fields by way of Parsons, Oswego, Columbus, Pittsburg, and into the entire zinc-mining district of southeastern Kansas and southwestern Missouri, where the company has an aggregate sale at retail price of close to fifteen million dollars per year. A portion of this is sold at the rate of twenty-five cents per 1000 cubic feet, but a much larger portion, that used for generating power, is at the rate of ten cents per 1000 cubic feet. Another pipe-line is carried westward to Wichita and beyond, connecting with all the intermediate towns. If we reckon this gas and that consumed by the cement plants, smelters, brickyards, and lesser manufacturing plants at three cents per 1000 cubic feet, the total production from Kansas alone for 1907 will have a value of between five and seven million dollars. Should it be estimated at the actual retail price, the total value would be very much greater, but here again the complexity is so great that this has not been attempted. The pipe-line companies make various rates to different factories, from less than ten cents upward, depending on the size of the factory and the particular kind of a bargain that may be made. Were the entire consumption paid for at specific rates, difficulties would not be so great.

Natural Gas in Oklahoma.—But little gas has been marketed from Oklahoma except for local consumption. One small pipe-line was laid across the state line near Caney and a large amount of gas is being conducted through it and delivered to the pipe-lines of the Kansas Natural Gas Company. The Secretary of the Interior and the state of Oklahoma are making efforts to prevent any further transportation of gas out of the

state. Early in the present session of the Oklahoma legislature a bill to that effect was passed and signed by the governor, and is now a law. It is very stringent, providing, among other things, at least according to newspaper reports, that no private individual shall pipe gas even within the state, the object being to make all pipe-line owners public corporations of record so that the authorities may the better cope with various attempts to get gas across the state line. Steps have already been taken to place the one pipe-line now crossing the state line into the hands of a receiver, hoping thereby to close it. In Oklahoma, consumption is confined almost entirely to domestic uses in the various cities and towns, for but few factories are as yet established. At Bartlesville, two zinc smelters are in operation and a third one is building. These give to that town an extra consumption. At Dewey, four miles north, the Portland cement plant has just begun operations.

The total value of gas in Oklahoma actually consumed in 1907 is approximately $1,500,000, the estimate being based on a rate of three cents per 1000 cubic feet. This statement, however, of itself, would convey an extremely imperfect idea of the possibilities of gas production in Oklahoma. Probably no other place in the world, now or at any other time, ever had so much gas developed ready for immediate consumption as has Oklahoma to-day. Natural gas occurs everywhere throughout all the productive oil-fields. Many wells range from fifteen to thirty million cubic feet per day, while a few are reported to have a capacity close to forty million cubic feet per day. The large amount of fuel now awaiting consumption is astonishing. And this, too, in face of the fact that all the development companies, with but few exceptions, have been trying to keep away from gas in their search for oil. What the result will be in the future when an intelligent search for gas is made no one can state at the present time, but the value of the annual production certainly will reach several million dollars.

Recent Developments in Kansas and Oklahoma.—In Kansas, considerable search was made for gas, the difficulty of piping gas from Oklahoma having served as a strong incentive. The most remarkable individual field discovered is about six miles southwest of Chanute. Here, on the high land between the Neosho and Verdigris rivers, a field has been developed almost entirely within the past year; some wells of this district

are so large as to compare favorably with the best of the wells drilled in Montgomery county two years ago. Wells ranging from two to thirty million cubic feet per day seem to be comparatively common.

Another commercially important field developed within the past year lies to the east of Fredonia. The wells here are not very large, ranging from three to five million cubic feet, but the field is so situated that the flow is consumed by various near-by manufacturing industries. In a similar manner considerable development has been made to the northeast of Chanute, or southeast of Humboldt, near the southern line of Allen county. This field extends eastward more than half way to Savonburg. The wells here, likewise, are comparatively small, but in the aggregate produce a large quantity of gas. Still another field of equal importance is just now being developed near Hale, in the northeast part of Chautauqua county. Wells from three to five million cubic feet per day are comparatively common.

An interesting small gas-field has been opened up near Elmdale, in the Cottonwood river valley, near Cottonwood Falls. Here is a well-marked anticlinal ridge. A member of the Kansas State Geological Survey suggested to certain citizens of Elmdale that it would be a good place to prospect for gas. Accordingly a number of wells were drilled only a few hundred feet deep and a flow of shallow gas was obtained. The wells vary in flow from 500,000 to 1,000,000 cubic feet per day. A similar condition exists to the southwest in the vicinity of Augusta, where shallow but good gas is obtained in a number of wells. The anticlinal ridge is not so fully marked there as at Elmdale. The now somewhat famous gas at Dexter is obtained from a similar anticlinal ridge, but the quality of the Dexter gas is so different from that at Elmdale and Augusta as to cause one to think that it comes from an independent pool.

The gas-field at Arkansas City continues to be very interesting. It is similar to the Augusta-Elmdale field. The gas is first-class in quality and is much greater in quantity than has as yet been developed at either of the other two places. A flow of gas has been developed sufficient to supply Arkansas City and still leave a surplus. What future developments will bring forth, of course, is largely conjecture, but it looks as though important developments may be expected in this district near and between Elmdale and Arkansas City.

In Oklahoma gas was found in many new wells along the ridge east of Bartlesville and north practically to the state line. A few large wells, in what appears to be the same field, were developed across the line in Kansas. South, along the Hogshooter, good gas-wells are also found. Here the gas lies underneath the oil, and frequently when a well drilled for oil goes dry it is carried deeper and a good gas-well obtained. The same is true regarding the region east of Collinsville, where wells having a capacity of from five to twelve million cubic feet per day are obtained. Also a number of good gas-wells have been obtained in the vicinity of Tulsa and west of Red Fork, in the district surrounding the Glenn oil-pool, and also near Muskogee. The boundaries of this last field have approached closer to Muskogee than was the case a year ago.

While no distinctly new field was opened up in Oklahoma during 1907, still gas was found in so many different places that the total possible production for the year was greatly increased.

Geology of the Field.—The oil and gas produced in the Mid-continental field, except that from the gas-wells in the Elmdale-Arkansas City district, and the Muskogee oil-field on the southeast, come mainly from Lower Carboniferous strata. In Oklahoma the westward development seems to result in deeper wells, so that the productive horizon remains about the same. In Kansas, however, there is a slight modification of this, and many of the oil-wells and gas-wells in the west part, near Longton and Howard, are not deeper than wells in the eastern part. This means that the productive horizon there is higher up geologically than in the heart of the field. Gas in the Elmdale-Arkansas City district is obtained fully 1000 feet higher geologically than the gas about Iola, Chanute and Independence. The mouths of these wells are in the Permian, but the productive sandstones are in the uppermost part of the Carboniferous. Some oil has been obtained at Muskogee from sandstones evidently below the Mississippian. Few attempts have been made elsewhere to penetrate the formations below the Mississippian except in the vicinity of Chelsea, Miami, and a few other points outside of the productive fields to the east. All of these wells, except those in the immediate vicinity of Muskogee, have been barren of oil and gas.

CHAPTER VII.

THE COMPOSITION OF NATURAL GAS, WITH SPECIAL STUDY OF THE CONSTITUTION OF KANSAS GASES.

By HAMILTON P. CADY *and* DAVID F. MCFARLAND.

SECTION I.

1. INTRODUCTORY.
   a. Early work on Kansas gases.
   b. Necessity of further work.
   c. The Dexter gas.
   d. Scope of present work.
   e. Bibliographies.
2. GENERAL CONSTITUTION OF NATURAL GAS.
   Description of chief constituents.
      Hydrocarbons:
         Paraffins—
            Methane.
            Ethane.
            Higher paraffins.
         Olefins—
            Ethylene.
            Higher olefins.
      Oxids of carbon:
         Carbon monoxid.
         Carbon dioxid.
      Nitrogen.
      Oxygen.
      Hydrogen.
      Gases of argon group.
         Argon.
         Helium.
         Neon.
         Krypton.
         Xenon.
      Hydrogen sulfid.
      Other constituents:
         Ammonia.
         Sulfur dioxid.

Introduction.

NATURAL gas is a substance of great importance to a large proportion of the population of Kansas. Something like a third of the state is deriving its heat and light from this source and consequently the composition of gas should be of personal interest to every citizen of this portion of the state, since the value of the gas for all purposes is directly dependent upon its chemical composition.

In the following report, the composition of Kansas natural gases has been taken up, and they have been compared with gases from other fields of the world.

The earliest work on the composition of Kansas natural gas

was done by Prof. E. H. S. Bailey, of the University of Kansas, who published in 1895[109] a report of the analyses of samples of gas from seven of the best gas-producing localities in the state. The results are given in the following table:

TABLE No. 1. EARLY ANALYSES OF KANSAS GASES.

CONSTITUENTS.	Paola.	Osawatomie.	Iola.	Cherryvale.	Coffeyville.	Independence.	Neodesha.
Carbon dioxid	0.33	0.22	0.90	0.22	0.00	0.44	1.00
Olefiant gas	0.11	0.22	0.00	0.00	0.35	0.67	0.22
Oxygen	0.45	trace	0.45	0.22	0.12	trace	0.65
Carbon monoxid	1.57	1.33	1.23	1.16	0.91	0.33	0.50
Marsh-gas	95.20	97.63	89.56	92.46	96.41	95.28	90.56
Nitrogen	2.34	0.60	7.76	5.94	2.21	3.28	7.07
Hydrogen	0.00	0.00	0.00	0.00	0 00	0.00	0.00
Totals	100.00	100.00	100.00	100.00	100.00	100.00	100.00

These analyses have been widely copied in various reports from this and other states and have been accepted as completely representative of all the gases from Kansas. They were carefully selected and did represent fairly the total gas supply then available, and are still typical of the better qualities of gas in the state as proven by the later work, but, nevertheless, the assumption that all the gas in this field has a similar composition is no longer warranted. Since these analyses were made the development of gas-producing wells in the older portion of the field has been very great and gas has been found in so many new localities and so much further west that a new and more extensive set of analyses was very desirable.

The present survey, while it has confirmed Professor Bailey's results for the localities represented, has shown that a wide difference exists in the composition of the gas from different portions of the state, particularly in the outlying and more recently discovered fields. It also indicates that the variation in composition follows some regular order, which apparently has some relation to the geological structure. It shows also that while most of the gases of the state are of high fuel value, certain ones are very low in combustible constituents and high in other more unusual components. The desirability of this survey was made apparent by the analysis of a curious and difficultly inflammable gas which was produced in extremely large quantities at Dexter, in Cowley county, in 1903. The following

109. Kan. Univ. Quart., July, 1895, vol. 4, pp. 1-14.

general account of the work done on this gas is taken from a paper by Cady and McFarland:[110]

"A sample was sent to the University of Kansas for analysis, and was found to contain only a small proportion of combustible constituents and a very large proportion of incombustible residue, such as is usually reported in gas analyses as nitrogen. The results of the analysis were published in a paper by Haworth and McFarland,[111] and by McFarland.[112] When the nitrogenous residue, mixed with oxygen, was subjected to the action of an electric spark over a strong solution of potassium hydroxid for a very long time, there was left a residue which refused to combine with the oxygen, and was evidently not nitrogen. This suggested the presence of some of the inert gases of the argon group.

"Further investigation of the Dexter gas by the methods described in this paper has shown the presence of considerable quantities of helium, and in a paper read for us by Prof. E. H. S. Bailey, at the New Orleans meeting of the American Chemical Society, we reported 1.84 per cent. helium. Since that time the investigation has been extended to many other Kansas natural gases, and also to gases from other fields, and in nearly every case helium has been found.

"Along with the determination of helium, an extended analysis of each gas has been made to determine its other more common constituents. . . ."

These analyses have revealed an interesting variation in composition with locality, which is discussed more in detail in the latter part of this report. In attempting to compare these gases with those from other fields, we have felt the lack of any considerable collection of natural gas analyses in the literature. The difficulty which we have experienced in finding this data, scattered as it is through a great mass of scientific journals and official reports, has led us to add to this paper a somewhat extended series of abstracts of analyses gathered from all available sources, together with references to the original papers. It is not claimed that these cover all of the work done on natural gas analysis, even in this country. Many analyses of gases from volcanoes, mineral springs and mines have been omitted intentionally, as not being quite in the same category as the natural gas used for industrial purposes. Enough of these have been given, however, for comparison, and it is

110. Jour. Am. Chem. Soc., 29, 1523. 1907.

111. Science, vol. 21, p. 191.

112. Trans. Kan. Acad. Sci., vol. 19, p. 60.

hoped that they may be of benefit to other persons in their investigations of the subject.

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6. List of Books, Papers and References on Rock Oil and Gas. U. S. Census Report, 1880, vol. X, p. 281. Penn. Geol. Surv., Ann. Rep. for 1886, pt. II, pp. 828-895.

General Constitution of Natural Gas.

Analyses of gas from many localities throughout the world have shown remarkably small numbers of constituents in widely varying proportions. The gas as it issues from the ground is always a mixture, often with one constituent in large excess of the rest, but still containing more than one gaseous substance. An enumeration and brief description of the more common constituents may be of use to those readers who are less familiar with the chemical nature of gas.

HYDROCARBONS.

The chief constituents of most inflammable gases belong to the family of hydrocarbons, compounds of hydrogen and carbon. These are all combustible and capable of producing con-

siderable heat by their combustion. Some of them are also light-producers, but these are present in such small quantities that a natural gas flame is usually nearly non-luminous. The hydrocarbons found in natural gas belong in two classes or series—the paraffins, or marsh-gas series, and the olefins, or the ethylene series. Some of the members of these two series are familiar as artificial products of the dry distillation of coal or wood, and are therefore usually found in coal- or producer-gas.

METHANE.—In natural gas the chief member of the marsh-gas series is methane, or marsh-gas itself, having the formula CH_4 and a composition of 25.03 per cent. hydrogen and 74.97 per cent. carbon by weight. The name marsh-gas comes from the fact that it is frequently produced by the decay of plants in swamps and the bottom of rivers. When pure it is a colorless, odorless gas, lighter than air and having a specific gravity of 0.559. A liter of the gas weighs 0.7148 grams and a cubic foot weighs 312.36 grains.

The boiling-point of liquefied methane, according to Ramsay and Travers, is —160.3° C.[113] Its critical temperature, that is, the temperature above which no amount of pressure will liquefy it, is —81.8° C.

It will be readily seen, therefore, that not even the highest pressures in the depths of the earth will suffice to hold it as a liquid if the temperature is above ordinary surface temperature, as is usually supposed to be the case.

When burned, one volume of methane unites with two volumes of oxygen, which is equivalent to ten volumes of air. The products of the combustion are two volumes of water-vapor and one volume of carbon dioxid. This production of water-vapor becomes apparent in the combustion of natural gas, the water condensing and collecting on any cold object near the burning gas. This gives rise to the popular belief that the gas as it comes in the pipes is wet or loaded with water. A simple calculation will show us the remarkably large amount of water produced in the burning of a thousand cubic feet of methane.

Each thousand cubic feet of methane produces on combustion twice its own volume, or 2000 cubic feet, of water-vapor. This weighs 100.13 pounds and is equal to approximately twelve U. S. gallons of liquid water. Now, if we have a natural gas containing 95 per cent. of pure methane, it would give 95

113. Boiling-points and critical temperatures of liquefied gases used here are taken from Travers' Experimental Study of Gases, London, 1901, p. 247.

per cent. as much water per 1000 cubic feet—that is, 95 pounds, or 11.4 gallons.

This shows that the production of a large quantity of water is an inevitable accompaniment of the combustion of natural gas, and it is no evidence of the good or bad quality of the gas itself, excepting that the quantity of water thus produced increases as the percentage of methane in the gas increases. It should therefore be considered rather a sign of good quality than of bad. The heat of combustion of methane is 966 British thermal units per cubic foot of gas, or 8598 kilogram calories per cubic meter.[114]

ETHANE.—Ethane, C_2H_6, the next member of the marsh-gas series, is sometimes found in considerable quantities in natural gas. It greatly resembles methane in its general properties, being a better fuel and burning with a slightly luminous flame, which makes it a better illuminant than methane. The heat value per cubic foot is 1728 British thermal units, or 15,387 kilogram calories per cubic meter.

Ethane contains 79.96 per cent. of carbon and 20.04 per cent. of hydrogen by weight. It boils at —93° C. under 760 millimeters pressure.

HIGHER HYDROCARBONS OF THE PARAFFIN SERIES.—Several more of the members of this series of hydrocarbons are found in small quantities in some samples of natural gas. As the members of the series increase in carbon contents and decrease in hydrogen there is a gradual change in properties. Some of the lower members of the series are:

	Formula.	Per cent. carbon.	Per cent. hydrogen.	Boiling-point.
Propane	C_3H_8	81.78	18.22	−45° C.
Butane	C_4H_{10}	82.72	17.22	+ 1° C.
Pentane	C_5H_{12}	83.19	16.81	+38° C.

As is seen in the above table, the boiling-points of these hydrocarbons rise with the increasing percentage of carbon, and consequently pentane and all of the still higher members of the series are liquids under ordinary conditions. These form the principal ingredients of petroleum. Their density and illuminating power increase in the same proportion and the odor grows stronger. The slight odor, resembling that of gasoline,

114. See Richard's Metallurgical Calculations, vol. I, p. 31.

which is noticed in some samples of natural gas, is usually due to the presence of these higher hydrocarbons. The amount of them which is normally present in the gas from wells is very difficult to determine satisfactorily. It is probable that only a long series of fractional distillations of the liquefied gases will prove conclusively the quantities present.

OLEFIN HYDROCARBONS.

The olefin series has as its most important representative in natural gas ethylene, or olefiant gas (C_2H_4). This contains 85.59 per cent. of carbon and 14.41 per cent. of hydrogen. It boils at —103.5° C. It burns with a much more luminous flame than the members of the paraffin series. Its presence in a gas would serve to increase its luminosity. It is, however, seldom found in more than a small fraction of a per cent. in American gases.

The other olefins have little interest as constituents of gas. It is possible that slight traces are present in some samples.

OXIDS OF CARBON.

Two more compounds of carbon are frequently reported in gas analyses: the oxids of carbon, one of which, carbon monoxid, is a fuel, and the other, carbon dioxid, has no fuel value whatever.

CARBON MONOXID.—Carbon monoxid, CO, a gas which may be produced artificially by the partial oxidation of carbon or carbon compounds, is colorless, odorless, and easily combustible, with a boiling-point of —190° C. It is especially to be noted for its poisonous qualities. A comparatively small amount breathed into the lungs produces death. One part in 300,000 parts of air produces poisonous effects, and a liter is a fatal dose. It is, however, a good fuel, with a heat value of 344 British thermal units per cubic foot, or 3062 calories per cubic meter, and is much used for that purpose in producer-gas, water-gas, and blast-furnace gas, in all of which it is the chief constituent. In natural gas it occurs only in very small quantities and is of little practical importance.

CARBON DIOXID.—Carbon dioxid, CO_2, is quite commonly found in natural gases, and, indeed, in some, especially those from mineral springs, it is the chief component. It has been found in Kansas gases in quantities up to two per cent. It is much heavier than air, having a specific gravity of 1.5241, and is incombustible, being itself a product of the combustion

or the slow oxidation of all carbon-containing materials. In combustible natural gas it acts as a diluent, reducing the fuel value of the gas.

NITROGEN.

Nitrogen is an inert, non-reactive elementary gas, and one of the chief constituents of atmospheric air. It is found in varying quantities in natural gas. In gas analyses it has been customary to denote as nitrogen any gaseous residue which resisted the action of the various absorbing solutions by which the other constituents were determined and which remained unburned after the removal of the carbon and hydrogen compounds by explosion. More recently it has been shown that this residue frequently contains, in addition to nitrogen, other inert gases, which resist to even a greater degree the action of oxidation and absorption. Such other constituents have been frequently reported from gases in mineral springs. In addition to this, our work, reported here, has proven the presence of these other inert gases in all of the Kansas gases examined. These facts make it probable that what has formerly been reported as nitrogen in most gas analyses has really consisted of a mixture of nitrogen with argon, helium, etc.

Nitrogen has been found in Kansas gases in quantities from 0.88 per cent. to 82.87 per cent. Being an unreactive element, nitrogen does not burn under the ordinary conditions of combustion and therefore has no value as a fuel. It serves simply to dilute the gases which have fuel value. In the Dexter gas, which contains the highest per cent. of nitrogen yet found in a Kansas gas, the effect of the large proportion of nitrogen is to make the gas extremely difficult to burn. It is not possible to light it in the ordinary way with a match. The small amount of methane mixed with such a large amount of nitrogen is diluted beyond the point where it can burn easily.

The very large proportion of nitrogen in this gas suggests a future possible use of it in the manufacture of calcium cyanamid or other nitrogen compounds for use as fertilizers, etc. (See general discussion, page 280.)

OXYGEN.

Oxygen is commonly reported in gas analyses, sometimes in considerable quantity. It is very doubtful as to whether more than mere traces should ever be reported. Since oxygen is an important constituent of atmospheric air, any admixture of air

with the natural gas would introduce a considerable percentage of oxygen; consequently, if oxygen is found in any considerable quantity suspicion is at once raised that the sample has become contaminated with air. Therefore a large percentage of oxygen reported in an analysis is viewed with suspicion, especially if it be accompanied by a correspondingly high amount of nitrogen, since this points to contamination of the gas sample.

HYDROGEN.

Hydrogen, a very light, highly combustible elementary gas, was formerly reported in large quantity in natural gases. In all probability this report was, in many cases, based on an incorrect interpretation of analytical results and upon faulty methods of analysis. The methods which at present seem best recommended for its determination show occasionally small percentages of hydrogen in the Kansas gases. Some of the best authorities on the analysis of natural gas, notably F. C. Phillips, whose work on the gases of Pennsylvania is of a very high order, are of the opinion that hydrogen is almost never a normal constituent of natural gas. Mr. Phillips cites this as an argument against the Mendelejeff carbide theory of the origin of natural gas.[115]

When present in a gaseous mixture free hydrogen has a considerable fuel value. Its heating power is 293.5 British thermal units per cubic foot, or 2613 calories per cubic meter. Owing to the erroneous reports of hydrogen in early gas analyses some doubt is cast on calculations of heat value based upon these analyses.

GASES OF THE ARGON GROUP.

These gases, argon, helium, neon, krypton, xenon, have been supposed to be of rather rare occurrence. Their presence in air was demonstrated by Rayleigh and Ramsey in the period from 1894 to 1898, and they have been shown to be present in gases from a number of mineral springs. Their complete lack of chemical reactivity and apparent inability to enter into any sort of chemical combination has rendered their detection very difficult and out of reach of the analyst in the ordinary ways. Recent methods of analysis, developed from the work of Dewar on the absorbing power of cocoanut charcoal at the temperature of liquid air, have greatly facilitated the separation of

115. Am. Chem. Jour., vol. 16, pp. 406-429.

these gases from mixtures and have made it possible to easily determine the presence and amount of at least the helium and neon in any gas. This has been done in the case of the present series of analyses, and the remarkable fact has been shown that helium is a constituent of every natural gas examined. Argon and neon have also been found in some of the gases, and it is probable that these also are universal constituents of natural gas.

The methods of determining the amounts of these and of krypton and xenon are still in such a condition as to make them difficult of performance.

Their importance in the gas lies not in any fuel value which they might have, because they are absolutely inert, so far as known, but rather in the utilization of the gas as a prolific source of these for experimental or other use. Already considerable quantities of helium have been extracted from Kansas gas and utilized in this way.

HYDROGEN SULFID.

This gas has been reported in a few analyses of American natural gas, particularly those made by Howard on Ohio and Indiana gases.[116] It is a somewhat disagreeable-smelling substance, and this fact usually makes its detection easy if it is present in any quantity. None of the Kansas gases have given this kind of evidence of its presence, and careful tests on several samples, by passing the gas through lead acetate solution, have shown none of it.

OTHER CONSTITUENTS.

Other substances which have sometimes been reported in gas analyses are ammonia and sulfur dioxid. The first has never been found in more than traces, while the second is practically never a constituent of commercial gas. It is sometimes found in gases from spring waters, particularly in volcanic regions, and is a normal product of volcanic action in some places.

From the above catalogue, it may be seen how few are the gases which enter into the mixture called natural gas, and this will be confirmed by a study of analyses.

116. See section II of this chapter.

SECTION II.

HISTORICAL REVIEW OF NATURAL GAS ANALYSES.

1. European work, 1830-1875 (analyses given in section V).
2. Gas analysis in America.
   Early work by Fouque.
   Later work; results presented by states:
   New York.
   West Virginia.
   Pennsylvania.
   Ohio.
   Indiana.
   Illinois.
   Iowa.
   California.
   Oregon.
   Utah.
   Colorado.
   Other states.
   Canada.

Historical Review of Natural Gas Analyses.

The analysis of gases in Europe was of a fragmentary nature up to 1850 and the methods used were inexact and extremely tedious.

It was not until Robert Bunsen developed his well-known set of methods for volumetric gas analysis that this became a reliable and convenient form of chemical investigation, and the work of this great chemist from 1836 to 1860 includes many such analyses. His researches on the composition of gases produced in geysers in Iceland were of great value, as were also his work on volcanic gases and on gases contained in mineral waters.[117] In 1857 he published the first edition of his "Gasometriche Methoden" the first good manual of gas-analysis methods.

Natural gas analyses published during the period from 1850 to 1875 were largely along the lines laid out by Bunsen. The gaseous products of volcanic action were actively studied, and a number of men, including Bunsen, Saint Clair Deville, Leblanc, Fouqué, S. de Luca, Ch. Vélain, Diego Franco, and O. Silvestri, made extended researches into gases from Vesuvius, Cerboli, and many other volcanic sources. References to a number of such papers are given in a later chapter, together with some characteristic analyses.[118]

Gases given off by mineral springs and in mines were also early subjects of investigation. The study of large supplies of natural gas for industrial use was almost unknown before

117. See section V of this chapter.

118. See section V of this chapter.

1875; chiefly because the large reservoirs of gas in America and Europe were still untouched.

Since 1875 there have been several more or less extended series of analyses made by European and American chemists. Some of these analyses are given in later portions of this report.

Review of American Natural Gas Analyses.

Taking up in detail the work that has been done on American gases, we may point out some of the principal results that have been obtained. These include all of the published analyses found in a rather extended search through the literature.

Early Analyses.

The earliest analyses were made in 1866 by M. Fouqué.[119] The analyses were not very complete, but indicated that the gases were composed chiefly of members of the marsh-gas series. His results are as follows:

TABLE No. 2.

Pioneer Run, Venango county, Pennsylvania.	Essentially composed of propane, C_3H_8, with small amounts of carbon dioxid and nitrogen. (N. B.—This turned out later to be a mixture of methane, CH_4, and butane, C_4H_{10}.)[120]
Fredonia, New York.	Mixture of methane and ethane, a small amount of carbon dioxid, and 1.55 per cent. of nitrogen.
Roger's Gulch, Wirt county, West Virginia.	Methane, 15.86 per cent. carbon dioxid, and small amount of nitrogen.
Burning Springs, Niagara river, below the cataract.	Almost pure methane, with a little carbon dioxid.
Petrolia, Enniskillen district, Canada, West.	Mixture of methane and ethane, with a little carbon dioxid.

This was the only work done prior to 1870 on American natural gases. Taking up now the analyses by American analysts, we shall consider them by states.

NEW YORK.

The early analyses of Fouqué, quoted above, included a sample of gas from Fredonia, N. Y. Prof. Henry Wurtz, in

119. Compt. Rendus, LXVII, p. 1045.

120. Report by Sam'l P. Sadtler, second Geol. Surv. of Pa., vol. L, p. 146.

1870, published an analysis of gas from West Bloomfield, N. Y.[121] The results were as follows:

TABLE No. 3.

Methane	82.41
Carbon dioxid	10.11
Nitrogen	4.31
Oxygen	0.23
Illuminating hydrocarbons	2.94
	100.00

Specific gravity, 0.693.

The methods used by this analyst were some absorption methods devised by himself and Prof. B. Silliman.

An analysis of gas from Olean, N. Y., by Robert Young, is given by Wm. A. Tilden.[122] No reference is made to the original paper:

TABLE No. 4. OLEAN, N. Y.

Methane	96.50
Carbon monoxid	0.50
Oxygen	2.00
Illuminating hydrocarbons	1.00
	100.00

Francis C. Phillips examined a sample collected from the mains of the Fredonia Natural Gas Light Company May 12, 1883:[123]

TABLE No. 5. FREDONIA, N. Y.

Nitrogen	9.54
Hydrogen	0.00
Carbon dioxid	0.41
Ammonia	0.00
Hydrogen sulfid	.....
Oxygen	trace.
Paraffins	90.05
	100.00
The composition of paraffins by weight—	
Carbon	78.14%
Hydrogen	21.86%

The only recent analysis which we have been able to find for New York gases is one made on the gas from Trenton lime-

121. Silliman's Journal, 1870, (2) 49, p. 336.

122. Journal of the Society of Chemical Industry, 4, 39 (1885).

123. Second Geol. Surv. of Pa., Ann. Rep. for 1886, pt. 1, p. 801.

stone at Baldwinsville, N. Y., by Dr. Durand Woodman.[124] This analysis is as follows:

TABLE No. 6. BALDWINSVILLE, N. Y.

Acetylene	0.00
Hydrogen (by palladium method)	trace.
Methane	98.40
Carbon monoxid	0.95
Carbon dioxid	0.00
Illuminants	0.25
Oxygen	trace.
Nitrogen (by difference)	0.40
	100.00

Specific gravity, 0.551, determined by W. W. Randolph.
Specific gravity—calculated, 0.558.
Heat units per cubic foot, 1013.5.

Orton (*loc. cit.*) considers that these figures may be taken with all confidence as representing the composition of the Trenton limestone gas of New York. This assumption is made in the face of the fact that the gas is held to be a shale gas, because it shows the following characteristics (*loc. cit.*, p. 469):

"1. No two wells draw their supply from exactly the same horizon. . . .

"2. No two wells have the same rock pressure, . . . a difference of several hundred pounds can sometimes be noted between closely contiguous wells.

"3. Salt-water is not found in any considerable quantities in any of the wells, and is entirely absent from most records even of wells that are drilled to the granite.

"4. No portion of the series from which the gas is derived shows porosity."

These facts are given by Orton, particularly characteristics 1, 2 and 4, as showing plainly that the wells have isolated sources, and they are so interpreted by him. Under these circumstances the assumption that an analysis from one of these wells represents them all is not in accord with the varied results in the Kansas field, where conditions are somewhat similar. (See p. 240.) Additional evidence that gases from the same locality may vary in composition even when coming from apparently the same source is given by Phillips's[125] results on the gases from six wells near Tarentum, Pa. These wells were situated nearly on a line, less than a mile long. The samples were all taken within an interval of three hours, and yet showed marked variation.

124. Edward Orton, Bull. of N. Y. Mus., vol. 6, No. 30, 1899, p. 467.

125. Am. Chem. Jour. 16, p. 412 (1894).

Consequently, the assumption made by Orton that one analysis will represent the composition of gas from any considerable area is somewhat unsafe, particularly if the gas is situated as he says these New York gases were.

WEST VIRGINIA.

The earliest analysis of a West Virginia gas was included in those made by M. Fouqué (see p. 239) on a gas from Roger's Gulch in Wirt county. The principal analytical work on West Virginia gas was done during June, 1904, by C. B. Howard, and published in a special report on oil and gas by I. C. White, state geologist.[126] These analyses are given as representing the average composition of West Virginia gases.

TABLE No. 7. WEST VIRGINIA NATURAL GASES.

	Sample No.—					
	1	2	3	4	5	6
Carbon dioxid	0.006	0.1	0.0	0.0	0.1	0.0
Carbon monoxid	0.4	0.4	0.4	0.4	0.4	0.5
Oxygen	0.2	0.2	0.2	0.1	0.3	0.3
Hydrogen	trace	0.2	0.0	0.1	0.1	0.0
Heavy hydrocarbons	0.4	0.2	0.4	0.2	0.1	0.2
Ethane	14.60	14.09	15.09	14.88	14.35	7.65
Methane	80.94	81.60	79.95	80.85	80.70	86.48
Nitrogen	3.46	3.21	3.96	3.47	3.95	4.87
Ammonia	none	none	none	none	none	none
Carbon bisulfid	none	none	none	none	none	none
Hydrogen sulfid	none	none	none	none	none	none
Moisture (grains per 100 cu. ft.)	17.72	.....	.....	.....	.....	.....
Total sulfur (grains per 100 cu. ft.)	0.182	.....	.....	.....	.....	.....
Total paraffins	95.54	95.69	95.04	95.73	95.05	94.13
B. T. U. per cu. ft. (calc.)	1,142.6	1,136.9	1,140.9	1,143.6	1,131.4	1, 65.3

NOTE.—Professor Jones reports B. T. U. slightly over 1100 by Junker calorimeter. Natural gas is taken as a standard (1000), assuming 94 per cent.

"Sample No. 1—Morgantown supply (Big Injun sand), Monongalia and Greene (Pa.) companies.

"Sample No. 2—Fairmont supply (Bayard sand), Marion county.

"Sample No. 3—Big Injun sand gas from Lucas Bros.' well No. 1, one mile and a fourth northwest of Shinnston. Top of sand 1421 feet below Pittsburg coal.

"Sample No. 4—Gordon sand gas (Shinnston supply) from J. B. Cunningham well No. 1, three and one-half miles northwest of Shinnston, Harrison county. Top of sand 2199 feet below Pittsburg coal.

"Sample No. 5—Fifth sand gas from Harbert well No. 1, near West Fork river, and three-fourths mile due east of Lumberport, Harrison county. Top of sand 2380 feet below the Pittsburg coal.

"Sample No. 6—"Fifty-foot" sand gas from Lucas Bros.' well No. 4, one mile west of Shinnston, near mouth of Robinson Run, Harrison county. Top of sand 1855 feet below the Pittsburg coal.

"The last four samples of gas were kindly furnished the Survey for analysis, as well as the records of the wells themselves, by the owner, The Fairmont & Grafton Gas Company."

126. W. Va. Geol. Surv., vol. 1 (a), 1904, pp. 553-556.

The methods by which the above analyses were made are described in the same report, pages 554 and 555. It is interesting to note that these analyses do not cover a very large field, and we would not be surprised if gases from other portions would differ markedly in composition. The only analysis of West Virginia gas which we have been able to make in the present series is one from Morgantown, W. Va., which was furnished to us under the direction of Dr. I. C. White, of the West Virginia Geological Survey. The results of this analysis may be seen in table 27, on page 270, analysis No. 39. The agreement with Howard's analysis, No. 1 in above table, is not bad.

PENNSYLVANIA.

Pennsylvania has long been noted as being the chief producer of natural gas in this country, and the attention of analysts was very early turned towards the discovery of the composition of Pennsylvania gas. The very earliest analyses of Pennsylvania gas were made by Fouqué, in the series already referred to. (See p. 239.) The first official series of analyses was made by Samuel P. Sadtler, published in 1875.[127] He used absorption methods for carbon dioxid, carbon monoxid, illuminating hydrocarbons and oxygen, and calculated the methane, ethane and hydrogen from the data obtained from explosion. In the following table each result is the average of two analyses:

TABLE No. 8.

	Burns Well, Butler county, Pennsylvania.	Leechburg, Westmoreland county, Pennsylvania.	Harvey Well, Butler county, Pennsylvania.	Cherrytree Spring, Indiana county, Pennsylvania.
Carbon dioxid	0.34	0 35	0.66	2.28
Carbon monoxid	trace	0.26	trace	.....
Olefins	.....	0.56	.....	.....
Hydrogen	6.10	4.79	13.50	22.50
Methane	75.44	89.65	80.11	60 27
Ethane	18.12	4 39	5 72	6.80
Propane	trace	trace	.....	.....
Oxygen	.....	.....	.....	0.83
Nitrogen	.....	.....	.....	7.32
Totals	100 00	100.00	99.99	100.00

Specific gravity of the Burns Well gas (calc.) 0.6148; (det.) 0.6977. Others were not determined.

As to the hydrogen in these analyses, see "General Discus-

127. Second Geol. Surv. of Pa., vol. L, pp. 152-160, 1875.

sion," p. 280 of this report. Doctor Chance[128] has also expressed doubts as to the accuracy of these analyses.

The following four analyses have been gathered from various sources, and are given as representing the composition of Murrysville gas, determined by different analysts at different times:

TABLE No. 9. ANALYSES OF MURRYSVILLE, PA., GAS.

	1	2	3	4
Carbon dioxid	0.00	.....	0 28	0 20
Carbon monoxid	1.00	.....	.....	.....
Heavy hydrocarbons	0.50	.....	.....	.....
Methane	95.20	78.24	*97.70	*95.4
Hydrogen	2 00	19 56	0.00	0.00
Oxygen	1.30	2.20	trace	trace
Nitrogen	0 00	.....	2 02	4 40
	100.00	100.00	100.00	100 00

*Total paraffins.

These analyses were made by analysts as follows:

1. Dr. G. Hay.[129]
2. Fuel Gas Company's well at Murrysville. Analysis by Rodgers (no reference given), quoted by Wm. A. Tilden.[130]
3. From Lyons Run, Murrysville. Analysis by F. C. Phillips.[131]
4. F. C. Phillips.[132]

The considerable variation in results of these analyses is probably due rather to difference in methods than to actual change in the composition of the gas. The work of Phillips on these and other analyses was done with extreme care and skill. It was mostly gravimetric and is worthy of great confidence. His conclusion as to hydrogen was checked in several ways by delicate methods, and we can have every assurance that hydrogen was absent from the samples which he examined.

The hydrogen in the other analyses was probably calculated from explosion data and consequently is open to doubt. (See "General Discussion," p. 280.)

A series of analyses was made by Mr. S. A. Ford, chemist of the Edgar Thompson Steel Works, in 1884.[133]

128. Pa. Geol. Surv., Ann. Rep. 1885, foot-note p. 675.

129. Eng. & Min. Jour., 39, 247.

130. Jour. Soc. Chem. Ind. 4, 39 (1885).

131. Second Geol. Surv. of Pa., pt. 2, 807 (1886).

132. Am. Chem. Jour. 16, p. 416 (1894).

133. American Manufacturers' Supplement, April, 1886; Jour. Iron and Steel Inst. 1885, vol. I, pp. 165-168; Ann. Rep. for 1885, Pa. Geol. Surv., p. 675, published in 1886.

Six samples, Nos. *a* to *f* were taken from the same well on the 18th, 25th, 28th and 29th of October, the 24th of November and the 4th of December, 1884. The analyses are supposed to show the variation in composition of the gas from this well:

TABLE No. 10.

	a.	*b.*	*c.*	*d.*	*e.*	*f.*	*h.*
Marsh-gas	57.85	75.16	72.18	65.25	60.70	49.58	67.00
Hydrogen	9.64	14.45	20 02	26.16	29 03	35 92	22 00
Ethane	5.20	4 80	3.60	5 50	7.92	12.30	5.00
Olefiant gas	0.80	0.60	0.70	0 80	0.98	0 60	1.00
Oxygen	2.10	1.20	1.10	0 80	0 78	0 80	0.80
Carbon monoxid	1.00	0.30	1.00	0.80	0.58	0.40	0 60
Carbon dioxid	0.00	0 30	0.80	0 60	0 00	0.40	0 60
Nitrogen	23.41	2.89	0.00	0.00	0.00	0.00	3.00

The variations above shown are truly remarkable, but since the data from which the hydrogen, methane and ethane were calculated were without much doubt obtained from explosion, the differences are probably apparent rather than real. (A little potassium hydroxid working into the burette from the carbon dioxid absorption pipette with each analysis would nearly, if not quite, produce all of these extraordinary results.)

What purports to be an average of the above six analyses is given in the annual report above referred to, page 676, and this has been rather widely quoted, but the figures cannot be obtained from those in the table by any ordinary method of averaging, and look like "happy means." They are given in the table under *h.*

Along this same line are the two following analyses of Grapeville, Pa., dry gas made by Mr. Morrell, chief chemist for the Cambria Iron Company, February, 1886:[134]

TABLE No. 11. ANALYSES OF GRAPEVILLE DRY GAS.

	Feb. 6.	Feb. 13.
Methane	35.08	14.93
Ethane	28.87	39.64
Nitrogen	27.87	18.69
Hydrogen	7.05	24.56
Olefiant gas	0.17	0.96
Oxygen	0.16	1.22
Carbon monoxid	0.22	trace
Carbon dioxid	0.58	trace
	100.00	100.00

What has been said above concerning the variation apparently found by Mr. Ford applies here as well. In a foot-note

134. Pa. Geol. Surv., Ann. Rep. 1885, p. 677, published in 1886.

on page 675 of the Pennsylvania report cited above, Doctor Chance expresses doubt as to the presence of any free hydrogen in the gases. He states that if the percentages of methane, ethane and hydrogen shown are added together and the results recalculated all variation in fuel value disappears. With respect to the subject of variation of composition of the gas from the same well, the work of Phillips[135] is of interest. Mr. Phillips determined the nitrogen content of the gas from a number of wells, and found that it varied somewhat from time to time. He did not test the gas for its other constituents. More reference will be made to this work later in this paper. (See "General Discussion," section IV, p. 280.)

What appears to be the most careful work that has been done on any gas analysis in America is that by Frances C. Phillips for the Pennsylvania Geological Survey during the year 1887, and published in the annual report of the Survey for 1886.[136] This report was published in the latter part of 1887. One of these analyses, that of the Murrysville gas, has already been given above in table 9. The others are given in the following table (No. 12).

Analyses Nos. 8, 9, 10, 11 and 13 are taken from a paper by Phillips.[137]

Phillips states (*loc. cit.*) that careful tests, including in some cases the passage of gas through solutions for weeks, have failed to show the presence of carbon monoxid or olefins in any of the gases examined. Oxygen seemed to be present in all samples but in quantities too small to be determined. Free hydrogen was reported only in the Speechly gas, where in the first report of the analysis 0.02 per cent. was given. In later reports of this same analysis he omitted the hydrogen, and in a paper[138] he says: "In many tests of gas made at the wells, and at intervals during several years in western Pennsylvania, I have failed to detect even traces of free hydrogen."

OHIO.

A number of reports on the occurrence of oil and natural gas in the state of Ohio have been published by the Ohio Geological Survey and by the United States Geological Survey.

135. Proc. Am. Acad., 34, 71-80 (1898).

136. Ann. Report Pa. Geol. Surv. for 1886, pt. 2, pp. 787-827.

137. Am. Chem. Jour. 16, 416.

138. Proc. Eng. Soc. of W. Pa., 13, p. 454 (1897).

TABLE No. 12. ANALYSES OF PENNSYLVANIA NATURAL GASES BY FRANCIS C. PHILLIPS.

CONSTITUENTS.	1 Sheffield, Warren county, Pennsylvania	2 Kane, McKean county, Pennsylvania	3 Wilcox, McKean county, Pennsylvania	4 Speechly, near Oil City, Pa.	5 Lyons Run, Murrysville, Pa.	6 Raccoon Creek, Pennsylvania	7 Houston, near Canonsburg	8 Murrysville, Pa.	9 Pittsburg Exhibition Grounds	10 Creighton, Pa.	11 Painter & Co.'s Well, Pittsburg, Pa.	12 Baden, Pa.	13 Allegheny City salt Well
Nitrogen	9.06	9.79	9 41	4 51	2.02	9 91	15 30	4 40	7 30	0.00	0 70	12 32	7 10
Carbon dioxid	0.30	0 20	0 21	0.05	0.28	trace	0.44	0.20	0.52	3 64	0 40	0.41	0 30
Hydrogen	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00
Ammonia	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0 00
Oxygen	trace	trace	trace	trace	trace	trace	trace	trace	trace	0 00	0 00	trace	0 00
Hydrogen sulfid	0.00	0.00	0 00	0.00	0.00	trace	0.00	0 00	0.00	0 00	0 00	0.00	0 00
Paraffins	90 64	90 01	90 38	95.44	97.70	90 09	84.26	95.40	92.18	96 36	98.90	87.27	92 60
Carbon monoxid	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00
Olefins	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0.00
	100.00	100.00	100 00	100 00	100.00	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00
Composition of above paraffins by weight:													
Carbon	76.69	76 77	76 52	77.11	74.96	76.42	76.68	75 15	75.40	75 80	75 51	76.48	75 44
Hydrogen	23.31	23 23	23.48	22 89	25 04	23.58	23.32	24 85	24.60	24 20	24.49	23 52	24.56

Nos. 1, 2, 3, 4, 5, 6, 7 and 12 are from Pa. Geol. Survey, Ann. Report, 1886, p. 815.
Nos. 8, 9, 10, 11 and 13 are from Am. Chem. Jour., 16, 416, 1894.

Very few analyses of the gas are given in these publications, and the little attention that has been devoted to the composition of the gas is remarkable in view of the large quantities which have been and are still used in the state.

The first analysis which we find is one recorded in Sadtler's report on composition of gas in Pennsylvania (*loc. cit.*) by Prof. I. S. Newberry and Professor Morley, who give the following composition of the gas from the Neff well, near Gambier, Ohio:

TABLE No. 13. NEFF WELL, GAMBIER, OHIO.

Oxygen	0.8
Carbon dioxid	0.3
Carbon monoxid	0.5
Methane	81.4
Ethane	12.2
Nitrogen	4.8
	100.0

Specific gravity: Calculated, 0.64; observed, 0.65.

An approximate analysis of Findlay, Ohio, gas was made by Emerson McMillan, superintendent of the Columbus gas-works, in 1885. He found the percentage of methane to equal or exceed 90 per cent.

About the only other published analyses of Ohio gases are those of Prof. Curtis C. Howard, of Starling Medical College. These have been much copied, and a number of references to them are given. No description is given of the methods used by Professor Howard in these analyses:

TABLE No. 14. ANALYSES OF OHIO NATURAL GASES BY C. C. HOWARD.

	1	2	3	4	5
Hydrogen	2 18	0 55	1.89	1.64	1 74
Methane	92 61	90 48	92 84	93 35	93.85
Olefiant gas	0 30	0 30	0.20	0.35	0.20
Carbon monoxid	0.50	0.15	0.55	0.41	0.44
Carbon dioxid	0 26	0.25	0 20	0 25	0.23
Oxygen	0 34	0 15	0.35	0 39	0.35
Nitrogen	3 61	8 12	3.82	3.41	2.98
Hydrogen sulfid	0 20	.....	0 15	0 20	0 21
	100.00	100 00	100 00	100 00	100.00

1. Gas from Trenton limestone at Findlay.[139]
2. Gas from the Thurston field, Clinton limestone.[139]
3. Fostoria gas, from Water-tanks wells.[140]
4. Findlay gas. Six wells of Findlay Gas Light Company.[140]
5. St. Marys gas. Wilkins well.[140]

139. Geol. Surv. of Ohio, 4th series, vol. 1, p. 125, Report on Oil and Gas.

140. These analyses are published in 8th Ann. Rep. U. S. Geol. Surv., pt. 2, p. 592; also, p. 646.

Francis C. Phillips, in his paper on "Composition of Natural Gas,"[141] gives an analysis of gas from Cleveland, Ohio:

TABLE No. 15. GAS FROM CLEVELAND, OHIO.

Nitrogen	6.30%
Carbon dioxid	0.20
Hydrogen	0.00
Ammonia	0.00
Oxygen	0.00
Sulfuretted hydrogen	0.00
Paraffins	93.50

The composition by weight of the paraffins was as follows: Carbon, 76.40; hydrogen, 23.60.

Olefins and carbon monoxid also tested for with negative results.

The only Ohio gas which we have had an opportunity to examine is that from Butler, in Richland county, south of Mansfield. (See table 27 of analyses, p. 270.) The gas is of good quality but seems to differ somewhat from the analyses published for other Ohio gases. This is quite to be expected because of its occurrence at some distance from those supplies.

INDIANA GASES.

Analyses by Prof. C. C. Howard, of Starling Medical College, Columbus, Ohio, in July, 1887,[142] show the composition of gas from four sources in the Trenton limestone:

TABLE No. 16. INDIANA GASES.

	1	2	3	4
Hydrogen	2.35	1 86	1 42	1 20
Methane	92 67	93.07	94 16	93.58
Olefiant gas	0 25	0 49	0.30	0 15
Carbon monoxid	0 45	0.73	0 55	0 60
Carbon dioxid	0 25	0.26	0 29	0.30
Oxygen	0 35	0 42	0 30	0.55
Nitrogen	3.53	3 02	2 80	3 42
Hydrogen sulfid	0.15	0.15	0 18	0.20
	100.00	100 00	100.00	100 00

1. Muncie, Ind., wells Nos. 1, 2, 3, 4 and 6.
2. Anderson, Ind., McCullough well.
3. Kokomo, Ind., wells Nos. 1 and 2.
4. Marion, Ind., well No. 3.

The Kokomo gas supply has also been analyzed by Francis C. Phillips.[143] His results are as follows, and show considerable

141. Am. Chem. Jour., vol. 16, 1894, p. 416.

142. Eighth Ann. Rep. U. S. G. S., pt. 2, p. 692.

143. Am. Chem. Jour. 16, 1894, p. 416.

variation, due probably to different methods rather than to any actual variation in the gas:

TABLE No. 17. KOKOMO, IND.

Nitrogen	6.00
Carbon dioxid	0.40
Hydrogen	0.00
Ammonia	0.00
Oxygen	0.00
Sulfuretted hydrogen	0.00
Paraffins	93.60

Percentage composition of paraffins by weight: Carbon, 75.40; hydrogen, 24.60.

Olefins and carbon monoxid, negative results.

It is interesting also to compare the above analysis of the Marion gas supply with the one which we have recently made. (See table 27, p. 270.)

Several discussions of the composition of Indiana gas are given in the various reports of the state natural gas inspector.[144]

In a paper on the "Utilization of Natural Gas," written by Elwood Haynes,[145] there is given the following composition of natural gas by weight:

TABLE No. 18.

Carbon	70.25
Hydrogen	21.45
Sulfuretted hydrogen	0.17
Carbonic acid	0.02
Nitrogen (by difference)	7.93
	100.00

No information is given as to the authorship of this analysis. Neither is any definite information given as to the analyst whose results on the "Composition of the Hydrocarbons in Natural Gas" are given on page 402 of the same paper. The analyses as given are:

Analysis made in 1894.		Analysis made in 1896.	
Carbon	76.4%	Carbon	76.8%
Hydrogen	23.6	Hydrogen	23.2

The available published analyses of Indiana gases cover only a comparatively small area of the gas-producing regions of the state. It would seem desirable that further work be done along this line on the gases from outlying districts and in more recently discovered fields.

144. Department of Natural Resources and Geology, Indiana: Vol. 18 (1893), p. 214; vol. 19 (1894), p. 139; vol. 20 (1895), p. 376.

145. Ibid, vol. 20 (1895), p. 401.

of gas from Stockton, Cal., quoted by R. S. Tarr.[150] The analyst is not named:

TABLE No. 23. STOCKTON, CAL., GAS.

Hydrogen	0.06
Methane	83.00
Ethylene	0.00
Carbon dioxid	0.05
Carbon monoxid	0.00
Oxygen	0.06
Nitrogen	....
Hydrogen sulfid	....
	83.17

An analysis which we ourselves made of gas from an oil-well in Los Angeles, sent us by Mr. Chas. R. Fletcher, 534 Stimson building, Los Angeles, is given among the original analyses in table No. 27, p. 270. The sample appeared to have air in it. It is chiefly noticeable as being the only one of the several gases examined from all localities which did not show some quantity of helium.

OREGON.

Natural gas is found occasionally in Oregon, as is shown in Prof. O. F. Stafford's Report on Mineral Resources and Mineral Industries of Oregon.[151] No analyses are given there, nor have any been found in the literature.

A gas sent to this laboratory in 1904 and stated to be from Oregon, the locality not given, was analyzed by H. P. Cady. The sample contained air, as is shown by the results:

TABLE No. 24. OREGON GAS.

Hydrogen	0.0
Higher hydrocarbons	0.0
Carbon dioxid	1.3
Carbon monoxid	0.0
Olefins	0.0
Oxygen	9.7
Methane	46.6
Nitrogen	42.4
	100.0

If this be figured to air-free gas it gives the following results:

Methane	88.1
Carbon dioxid	2.4
Nitrogen	9.5
Olefins	0.0
Higher hydrocarbons	0.0
Carbon monoxid	0.0
Hydrogen	0.0
	100.00

150. Economic Geology of the United States, p. 350.

151. Univ. of Oregon Bull., vol. 1, No. 4, 1903, p. 103.

We do not regard this analysis as having any particular value, but it is the only one of an Oregon natural gas of which we have any knowledge.

UTAH.

In a report on "Natural Gas near Salt Lake City, Utah," by G. B. Richardson,[152] is an analysis of the gas collected at the wells, 500 to 600 feet deep, in 1894, and analyzed by Prof. J. T. Kingsbury and others:

TABLE No. 25. SALT LAKE CITY GAS.

Methane	22.3
Ethane	37.8
Ethylene	0.7
Carbon monoxid	1.2
Carbon dioxid	0.8
Hydrogen	16.6
Nitrogen	19.7
Oxygen	0.9
	100.0

In commenting on the somewhat remarkable figures of this analysis, F. C. Phillips[153] asserts that the hydrogen determination must be in error. He describes a very delicate method and apparatus by which he tested this gas thoroughly for hydrogen. None was found to be present.

COLORADO.

Few analyses are available of gases occurring in Colorado. Neither of the ones which we have found published are of combustible gases. Their interest lies rather in their high percentage of nitrogen, which is of importance in relation to the Dexter, Kan., and the Princeton, Ill., gases.

Harry A. Lee[154] describes a gas which issues in great quantity from a highly brecciated portion of a great fault fissure-vein, in the Happy Thought mine, near Creede, Colo. The gas is lighter than air, seeking the upper portion of drifts, and is more abundant at times of low barometric pressure, disappearing almost completely when the pressure is high. The outflow or inflow through openings in the breasts of drifts is at times sufficiently powerful to be distinctly audible and to blow the flame of a candle nearly horizontal. An analysis by W. F. Edwards showed oxygen, 3.92 per cent.; nitrogen, 96.08 per cent.

No statement is made as to whether the concentration of

152. Bull. No. 260, U. S. Geol. Surv., p. 481. 1904.

153. Proc. Eng. Soc. of West. Pa. 13, 453.

154. Proc. Colo. Sci. Soc., 7, 163-188.

nitrogen in the gas has been due to abstraction of oxygen of air by sulfids or whether the nitrogen has come from the depths.

A somewhat similar occurrence of gases high in nitrogen in metalliferous mines is noted by Lindgren and Ransome.[155] In several of the deeper mines of the Cripple Creek district gases issue from the breccia, frequently in such large volumes as to cause great inconvenience and at times force the abandonment of work for days at a time. The gas is often very heavy, filling lower parts of drifts and winzes like water, and cases are reported in which it has actually been bailed from a shaft. Its temperature is somewhat higher than that prevailing in the mine under normal conditions. It is tasteless and odorless, but produces suffocation and extinguishes flame. Analyses of samples collected have shown a small amount of oxygen, about twenty per cent. of carbon dioxid and the remainder nitrogen.

These gases are believed by the authors of the above-mentioned paper to be of volcanic origin.

OTHER STATES.

Natural gas is produced in some quantity in several other states of the Union. Among these may be mentioned Texas, Wyoming, Montana, Missouri, South Dakota, Tennessee, Oklahoma, Louisiana.

Very little analytical work has been published concerning the gases obtained in these states. In table 27, p. 270, we have shown the results which we have obtained from a few gases from Missouri, Oklahoma, South Dakota and Louisiana. We would be very much interested in seeing the composition of gas from other localities in the same states and in the states which are not represented in any of the above tables.

CANADA.

Natural gas is reported as a resource of considerable value in at least one Canadian province, Ontario. We have been unable, however, to find any published analyses in the literature at our disposal. Two analyses of Canadian gas have been published by Francis C. Phillips. One[156] is a gas from a well at Point Albino, Canada, ten miles west of Buffalo. The other is

155. Geol. Resurvey of the Cripple Creek District, Colorado. Bull. No. 254, U. S. Geol. Surv., p. 32.

156. Jour. Am. Chem. Soc., 20, p. 700, 1898.

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155. Geol. Resurvey of the Cripple Creek District, Colorado. Bull. No. 254, U. S. Geol. Surv., p. 32.

156. Jour. Am. Chem. Soc., 20, p. 700, 1898.

from Vancouver, British Columbia.* The results shown are as follows:

TABLE No. 26.

	Point Albino, Canada.	Vancouver, British Columbia.
Methane	96.57	93.56
Ethane	0.00	
Hydrogen	0.00	0.00
Carbon monoxid	0.00	0.00
Carbon dioxid	trace	0.14
Nitrogen	2.69	6.30
Hydrogen sulfid	0.74	0.00
	100.00	100.00

SECTION III.

ANALYSES OF KANSAS NATURAL GAS.

1. Collection of gases.
2. Methods of analysis—calculations, formulæ, etc.
3. Determination of helium, neon, argon, etc.
   - *a.* Apparatus.
   - *b.* Method of analysis.
4. Analytical results.
   - *a.* Data concerning gases analyzed.
   - *b.* Table of analyses.
   - *c.* Discussion of results.
     - Variation in composition.
     - Distribution of constituents.
     - Isohelium and isoparaffin lines.
     - Origin of helium, etc.
     - Conclusions.
5. The heating power of Kansas gas.
   - *a.* Methods of determining.
     - Calculation from analysis.
     - Calorimetric determination.
       - Relative value of results.
   - *b.* Principle and use of the gas calorimeter.
   - *c.* Experimental work on heat values, pipe-line gas.
     - Calorimetric determinations.
     - Analysis of same sample.
     - Calculation of heat value from analysis.
     - Comparison.
   - *d.* Importance of heat determination.
     - Effect of dilution of gas by nitrogen on heat value.
     - Need of laboratory check on both composition and heat value.

Analyses of Kansas Natural Gas.

The work given below was done in the laboratories of the Department of Chemistry of the University of Kansas during the years 1905-1907. A considerable part of the results have already been published in a paper by Cady and McFarland,[157] and the authors have made a number of abstracts from this paper in the present chapter. Additional analyses have been made since this publication, and some calorimetric work has been done.

* Am. Chem. Jour. 16, 1894, p. 416.

157. Jour. of Am. Chem. Soc., 29, 1523-1536 (1907).

COLLECTION OF GASES.

Much of the work of collecting the samples of gas for analysis was done by members of the University Geological Survey, and the cost of collection was in most cases borne by the Survey.

Several strong steel and tin cylinders, of a variety of shapes and sizes, were adapted to the needs of the work. Stop-cocks were put at each end of the cylinder, fitted with caps to prevent leakage. The tin cylinders were shipped in galvanized iron carrying-cases, which protected them from injury. At the gas-well both ends of the cylinder were opened and one end attached by a secure connection to the source of gas. The gas was then allowed to flow through the cylinder, at a considerable pressure if possible, for several minutes to insure the complete driving out of all air. This was found to be quite effective when properly carried out. Then the stop-cock at the end of the cylinder opposite to that at which the gas was entering was closed tightly and the gas allowed to accumulate in the cylinder. In the tin cylinders a pressure of fifty pounds was often carried, while in the steel cylinders the entire well-pressure of several hundred pounds could be reached. When this maximum pressure had been attained the cylinder was tightly closed and shipped to the laboratory.

When received at the laboratory, enough gas was taken from the cylinder to fill a large glass gasometer in which the gas was confined over distilled water. This constituted the portion for the extraction of helium. At the same time a small flask was filled with gas for analysis. The determination of helium and the complete analysis were carried out immediately whenever possible, and if any delay was necessitated, it was made as short as possible, and precautions were taken to avoid contamination of the sample or absorption of carbon dioxid.

METHODS OF ANALYSIS.

For the determination of the constituents of the gas other than the rare elements of the argon group, the standard methods of Hempel were used. In a 100-cubic-centimeter portion of the gas the determinations were made in the following order: Oxygen was absorbed in a phosphorus pipette; carbon dioxid in strong potassium hydroxid solution; ethylene and the olefins in fuming sulfuric acid, followed by potassium hydroxid; and, finally, carbon monoxid in ammoniacal cuprous chlorid.

After the determination of carbon monoxid, a portion of the residue, usually about 20 cc., was measured off, mixed with pure oxygen and air in such a manner as to give a proper excess of oxygen, and exploded over mercury. The contraction in volume, and the amount of carbon dioxid produced, were determined in the usual manner, taking precautions to avoid, as much as possible, the error introduced by the absorption of carbon dioxid in the water produced by the explosion, which error may be considerable if haste is not used in the measurement of the volume after explosion. The residual oxygen was then determined by means of the phosphorus pipette in order to show both its amount and also that of the residual nitrogen. Frequent readings of barometer and thermometer enabled corrections to be made for changes in temperature and pressure.

From the explosion data the quantities of methane and ethane were calculated, assuming that these were the only paraffin hydrocarbons present; an assumption which is not entirely warranted, because of the fact that it was found possible to condense higher-boiling hydrocarbons along with the methane in a bulb surrounded by liquid air. Some of these remained liquid up to ordinary temperatures and had an odor similar to that of light-boiling petroleum distillates. The quantity of this residue varied in the different gases. It has seemed practically impossible to get at the amounts of these substances by explosion methods, and for the present the above assumption will be made. It seems probable, however, that they may be determined by the fractional distillation of the liquefied gas, and work along this line is being carried on in this laboratory.

The formulæ used in the calculation were as follows:

For Methane:

(1) $CH_4 = 4\ O_2 - 7\ CO_2$
(2) $3\ CH_4 = 4$ Cont. $- 5\ CO_2$
(3) $4\ CH_4 = 7$ Cont. $- 5\ O_2$

For Ethane:

(1) $C_2H_6 = 4\ CO_2 - 2\ O_2$
(2) $C_2H_6 = O -$ Cont.
(3) $3\ C_2H_6 = 4\ CO_2 - 2$ Cont.

Each one involves two of the following factors: Contraction on explosion (Cont.), carbon dioxid (CO_2) formed during the explosion, and oxygen (O_2) used up in the explosion.

A small error in the measurement of any of these quantities is apt to produce large error in the calculated results. (See "General Discussion," section IV, p. 280.)

For the determination of hydrogen, a portion of the residue from the absorption of carbon monoxid was used. It was found that the data from explosions were entirely too unreliable for the calculation of hydrogen, and the combustion of the hydrogen, mixed with air, over palladinized asbestos, was adopted. In order to insure the combustion of only the hydrogen on heating to a constant temperature of 100°, the U-tube containing palladinized asbestos was surrounded by a Dewar vacuum-jacketed tube, containing water which was kept at the boiling-point by a platinum coil heated by the passage of an electric current. Several determinations of hydrogen in mixtures of known composition proved the efficiency of this arrangement. With the electrical heating device a constant temperature could be maintained, while the vacuum jacket around the bath prevented effectually the heating of the apparatus outside the U-tube.

In the great majority of cases no hydrogen was found, and it is possible that where it seemed to be present a part of the effect may have been due to the presence of small quantities of higher hydrocarbons.

Charitschkoff[158] says that the method of fractional combustion of hydrogen and methane, with palladium asbestos, is inapplicable to some natural gases because of the presence of higher hydrocarbons, such as isopentane, etc., which are oxidized with the hydrogen.

These statements are not in accord with the work of F. C. Phillips,[159] who has elaborately investigated the phenomena of oxidation of hydrogen and the hydrocarbons in the presence of palladium and other catalyzing agents.

DETERMINATION OF HELIUM.

For the determination of helium, use was made of the property of cocoanut charcoal of absorbing all gases except helium, neon and hydrogen, when cooled with liquid air. This property was discovered by Dewar.[160] It is our experience that hydrogen is rather freely absorbed, neon much less than hydrogen, and helium so slightly that all but an infinitesimal trace can be removed by pumping with a mercury pump.

158. J. Russ, Phys. Chem. Soc., 1902, 34, 393-395. Jour. of Chem. Soc., A II, 529, 1902.

159. Am. Chem. Jour., 16, 163-187.

160. Chem. News, vol. 90, p. 90 (1904).

APPARATUS.

The apparatus used is shown diagrammatically in figure 6. *A* is a condensing bulb, in which, when surrounded by liquid air, the greater part of the methane and other hydrocarbons contained in the natural gas can be liquefied. *B* and *C* are bulbs containing twenty grams of cocoanut charcoal each. *D* and *G* are U-shaped glass tubes which, when immersed in liquid air, hold back water- and mercury-vapors. This is by far the simplest and most effective method of preventing the diffusion of mercury-vapor into the spectral tubes used. The actual apparatus is so constructed that *D* and *G* may both be immersed in the same vacuum tube. *H* is an automatic Sprengel air-pump, the mercury being returned to the reservoir in the form of small drops by the suction of a Chapman pump. *I* is the receiver for collecting helium; *F* and *E* are Plücker tubes. *F* is a permanent part of the apparatus; *E* is filled with the gas and sealed off for later examination with a large spectrometer.

To prepare the apparatus for an analysis, a good water-pump was connected to the charcoal bulbs at *J*, and dry air drawn through the apparatus to remove all gases left from the previous analysis. The connection with the outer air was then cut off and the whole exhausted as thoroughly as possible with the water-pump, heating the charcoal bulbs strongly at the same time. When exhaustion had been carried to the limit of the water-pump the Sprengel pump was put into operation, and the pumping continued until practically all the air had been removed. The charcoal bulbs were allowed to cool and then immersed in liquid air. The vacuum quickly became so good that a spark would not pass through the Plücker tubes. The apparatus was then ready for use.

METHOD OF ANALYSIS.

The gas for analysis was taken from the gasometer containing it and the amount used was determined from the weight of water which displaced it, making all necessary corrections for temperature and pressure. The bulb *A* was first filled with water, inverted, and the water displaced by the gas. It was then surrounded with liquid air and put into connection with the gas-holder. If the gas did not contain more than fifty per cent. of nitrogen, from twelve to fifteen liters would quickly pass into the bulb. A large amount of nitrogen seems to dis-

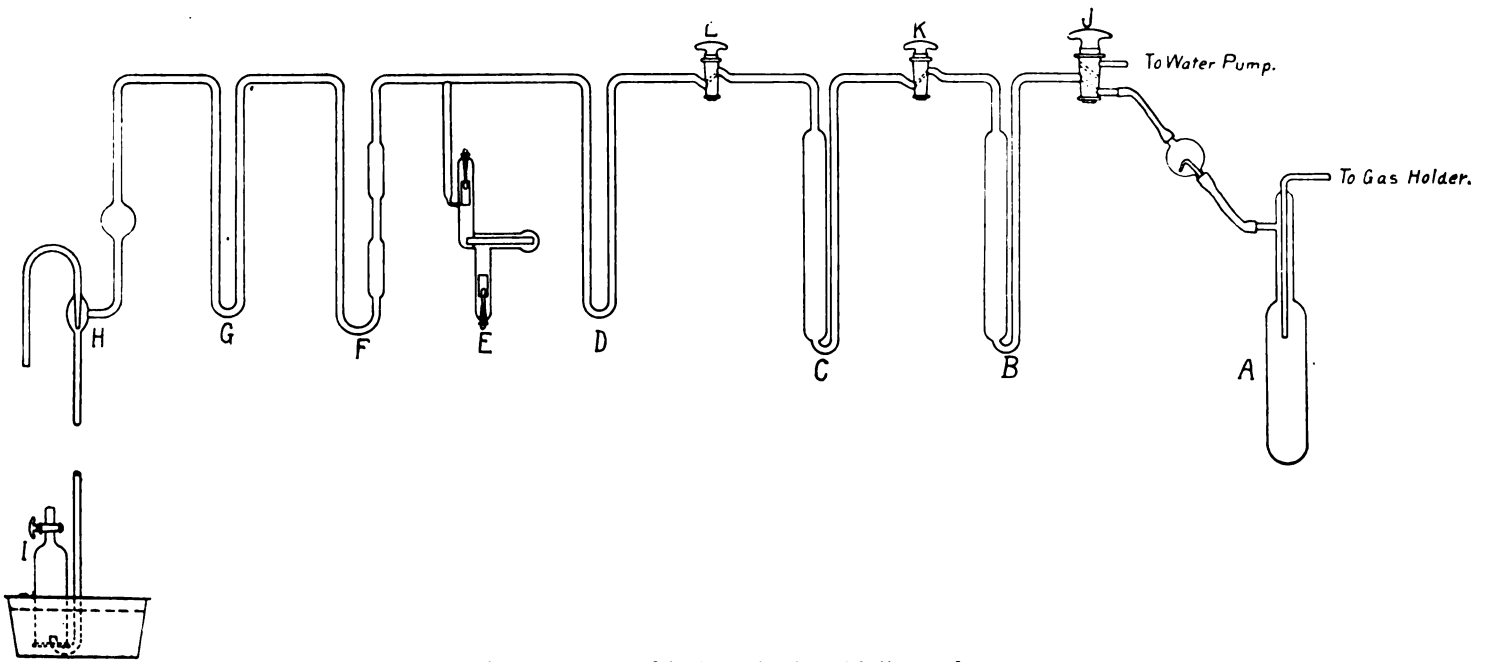

FIG. 6. Apparatus used in determination of helium and neon.

solve in the liquid methane. When the desired amount of gas had passed into *A* the connection with the gas-holder was closed, and after standing for several minutes the stop-cock leading into *B* was opened for a moment, that between *B* and *C* being closed. The gas was held in *B* for five minutes to allow the absorption of everything except the helium. Stop-cock *L* being closed, the gas was passed into *C* and allowed to stay there another five minutes, and finally admitted to the Plücker tubes and pump. Here it was examined with the spectroscope, removed by means of the pump, and collected in *I*. When the pressure in the system became low, stop-cock *K* was closed and more gas admitted into *B* from *A*, allowed to stand, passed into *C*, and finally, after standing there the required time, the connection to the pump was again opened. This entire series of operations was repeated until no more helium could be obtained. It has been repeatedly proven by our experience that practically all the helium may be removed by this process. Towards the end of the operation, when the pressure in the entire system was low, the liquid methane solution in *A* could be made to boil even when surrounded by liquid air, and this insured the removal of all the helium from the bulb. It might be mentioned, in passing, that the freezing-point of the methane was lowered by the nitrogen, etc., so that only part of it solidified in *A*.

With care all the helium could be transferred to the charcoal bulb without permitting so much nitrogen to pass over as to saturate the charcoal. The purity of the gas could be insured by watching the spectrum, and if there was any suspicion of nitrogen the apparatus was prepared as for a new analysis and the gas run through again. The operation was tedious, but not more so than most gravimetric determinations.

By essentially the same method, but using larger charcoal bulbs, considerable quantities of helium have been obtained, and a still larger apparatus is being constructed.

That the gas obtained in these experiments is helium is proven by the fact that all of the visible lines of helium catalogued have been observed, the wave-lengths agreeing, within the limits of error, with the accepted values. This is also established by direct comparison of the spectra with those given by known specimens of helium.

The spectrometer in use for the examination of the gases is a new Pulfrich auto-collimating instrument made by Zeiss. It

is very powerful and quite satisfactory. Readings can be taken rapidly and the duplicates agree closely.

The new form of end-on tubes made by Goetze (see *E*, fig. 6), when filled with gases of the argon group, give beautifully sharp spectra.

The helium obtained as above practically always shows hydrogen lines and carbon bands, the latter, most likely, from a trace of carbon monoxid, but these two impurities are present in such small quantities that the contraction produced on exploding a mixture of the helium with pure oxygen and electrolytic gas is too small to measure. During the analysis of the gas no neon was detected, but later, during the preparation of larger quantities of helium from some of the gases, neon was found. The quantity was not determined, but it is certainly small compared to that of helium in the same gas. Argon was also found, as will be described.

ISOLATION OF NEON.

The method for the isolation of this gas is briefly as follows: The natural gas is largely condensed in a bulb surrounded by liquid air. The uncondensed portion is then passed into bulbs filled with cocoanut charcoal and cooled with liquid air. As has already been said in the above description of the separation of helium, all the gases in the mixture except hydrogen, neon and helium are completely absorbed. Of these three gases hydrogen is rather freely absorbed, neon somewhat, and helium scarcely at all. In working with small quantities of gas, such as is done in an ordinary analysis for helium, the neon is very largely taken up by the charcoal and consequently does not show in the spectral tube. With larger amounts of gas the charcoal finally becomes saturated with neon, and then its lines are plainly visible in the spectrum of the residue. The difference in the absorption of helium and of neon is great enough so that neon spectroscopically free from helium may be prepared as follows: A charcoal bulb is heated to about 400° C. and exhausted as completely as possible, using the mercury-pump. It is then cooled with liquid air and the unabsorbed gases from another charcoal bulb are passed in, allowed to stand for a time, and removed with a mercury-pump. After a sufficient amount has been passed through the bulb, the helium is removed by pumping until a cathode-ray vacuum is obtained. The bulb is then warmed slightly and some gas removed. After this, by warming the bulb more strongly, neon spectroscopic-

ally free from helium is obtained. The identity of the neon was established by measuring the wave-lengths of the lines in the spectrum, using the above-described spectrometer and comparing them with those given by Baly.[161] Baly photographed something over a hundred lines in the visible portion of the spectrum. About half of these lines are given as very faint. We have measured optically about sixty-five of these lines, including all but the very faintest. The measurements, with one exception, agree with Baly's to within one Ångström unit. In this case it is quite evident that there is a misprint in Baly's table, for our measurement agrees well with that given by Living and Dewar[162] for this line, while it differs from Baly's by much more than the limit of error.

Besides the lines of neon, the tubes show about fifteen fairly strong lines which do not seem to belong to hydrogen, helium, or any of the familiar gases. These lines are given in a list of lines shown by the more volatile gases of the atmosphere and by the gases from Bath Springs, as published by Living and Dewar (*loc. cit.*) This would seem to show that the lines are not accidental, and that it is legitimate to look for a new very volatile gas in this residue.

DETECTION OF ARGON.

Since argon has a higher boiling-point than liquid air it is almost entirely condensed in the first bulb of the above apparatus with the methane of the gas. Consequently no argon can be detected by the use of this apparatus. The method which we have thus far utilized for determining its presence is as follows: The incombustible nitrogenous residue from the gas is first nearly freed from nitrogen by passing over a mixture of metallic magnesium and calcium oxid in a tube heated to high redness. The residue is completely freed from nitrogen by sparking with pure oxygen over a potassium hydroxid solution. After removing the oxygen from the gas thus left by introducing pellets of phosphorus, the residue, which now contains only gases of the argon group, is introduced into a cocoanut charcoal bulb which has been previously completely freed from gases by heating it to a rather high temperature and exhausting with the mercury-pump. The bulb is cooled with liquid air and after the gases have been in contact with the

161. Phil. Trans., 1904, vol. 202, p. 183.

162. Proc. Roy. Soc., 67, 467, 1901.

cooled charcoal for some time, the helium and neon are removed by strong pumping with the mercury-pump, which is kept going until helium can no longer be detected by the spectroscope and the vacuum is very high.

Then the charcoal bulb is allowed to warm up, thus allowing the argon to pass out of it. The lines of argon immediately appear in the spectrum and are identified by careful measurement of their wave-lengths and by comparison with those from known specimens of argon.

The tedious nature of this operation, and also that for the detection of neon, have prevented us from testing many gases for them. It may be remarked, however, that neon is a usual constituent of the gas furnished to the University through the pipe-lines of the Kansas Natural Gas Company and has been several times extracted from this source. Argon is present in the Dexter gas. It is probable that both gases will be found as normal constituents of most of the samples of natural gas, if they are tested for.

KRYPTON AND XENON.

We have in hand the concentration of a considerable amount of Dexter gas, and propose, when a sufficient amount of the inert residue has been obtained, to test for krypton and xenon. It is our expectation that by means of cocoanut charcoal bulbs held at the proper temperatures the separation of the entire series of gases of the argon group may be effected.

HYDROGEN SULFID.

This gas was tested for in several of the gases examined by passing the gas for several hours through solutions of lead acetate and copper sulfate. In no case was any precipitate produced, and from this fact and the fact that no odor of hydrogen sulfid has been detected in any of the gases examined, we conclude that hydrogen sulfid is not present, except in the very faintest traces.

ANALYTICAL RESULTS.

The results of the analyses are given in table 27. The analyses are arranged in the order of the quantity of helium contained in the gases. A statement of such data as were obtainable regarding the location, depth and pressure of the wells producing the gases, as well as other matter of interest regarding their occurrence, is appended to the table.

DATA CONCERNING COLLECTION OF GASES ANALYZED.

1. Dexter, Kan. Original sample. Collected in 1905 from well supplying town. Depth, 310 feet. Pressure, 110 pounds. Capacity, six million feet.

2. Gas from Kansas Natural Gas Company's pipe-line at Lawrence, Kan. Comes from near Chanute, Kan. Composite from several wells. Sample taken October 23, 1905, about one week after gas was first turned on.

3. Pipe-line gas. Same general source as No. 2. Sample taken at Lawrence, May 16, 1906.

4. Eudora, Kan. Collected from town mains. Comes from wells in town, 350 feet deep. Pressure, 200 pounds.

6. Dexter, Kan. Greenwell well. Depth and pressure similar to No. 1. Collected June 12, 1906.

7. Iola, Kan. City supply. Collected from mains at office of Iola Gas Company, June 10, 1906.

8. Moline, Kan. Collected June 24, 1906. From wells south, east and west of Moline. Average depth, 1150 feet. Average pressure, 380 pounds.

9. Fredonia, Kan. Town supply. Wells from two to seven miles east, south and northwest of town. Depth from 1085 to 1250 feet. Pressure from 300 to 480 pounds.

10. Neodesha, Kan. Collected June 27, 1906. Some air in the sample.

11. Lawrence, Kan. From an old well, about 1200 feet deep. Only slight flow of gas, escaping with salt-water. Collected July 4, 1906.

12. Erie, Kan. City supply. From wells north and east of town, within two miles. Depth, 510 feet. Pressure, 150 pounds. Sample collected July 3, 1906.

14. Bartlesville, I. T. Received July 8, 1906. Air in the sample.

15. Bonner Springs, Kan. Collected July 8, 1906. From wells averaging 600 feet in depth, and 190 pounds pressure, belonging to the Bonner Portland Cement Company.

16. Parsons, Kan. Gas supplied by pipe-line to city of Parsons. Comes from wells in Eson district, in southeastern part of Wilson county, Kansas, belonging to the Prairie Oil and Gas Company.

17. Arkansas City, Kan. City supply. From well 750 feet deep, with pressure of 355 pounds and capacity of five to six million feet.

18. Altamont. Gas collected from Kansas Natural Gas Company's pipe-line supplying Joplin district. Comes from near Liberty and Coffeyville, in Montgomery county. Coffeyville wells are about 950 feet deep and have a pressure of 450 pounds. Sample is a composite, representing the district.

20. Moran, Kan. Collected July 13, 1906. No data.

21. Iola, Kan. City supply. A composite sample from several wells. Collected July 13, 1906, from mains at city gas office.

22. Caney, Kan. From a well two miles east of Caney. Pressure, 620 pounds. Depth, 1550 feet. Belongs to Caney Gas and Mining Company. Collected July 14, 1906.

23. Peru, Kan. Collected July 20, 1906. No data.

24. Butler, Ohio. Richland county. Collected July 19, 1906, from well belonging to Frank O. Levering. Well pressure is 1200 pounds.

25. Chanute, Kan. City supply. From wells east of city. Composite sample. Depth, 850 feet. Pressure averages 200 pounds. Collected July 24, 1906.

26. Humboldt, Kan. Composite sample from low-pressure mains of city supply. Collected July 23, 1906.

27. New Albany, Kan. Received July 25, 1906. No data.

28. Altoona. Received July 25, 1906. No data.

31. Buffalo, Kan. Sample from well inside of town. Collected July 28, 1906.

32. Blackwell, Okla. Received from J. W. Beatty, July 31, 1906. Taken from well No. 2, of Union Gas and Oil Company. Depth, 640 feet. Pressure, 185 pounds. Capacity, one million feet.

33. Garnett, Kan. Sample collected August 1, 1906, from mains bringing in town supply from wells east of town. Average depth, 600 feet. Average pressure, 200 pounds.

34. Olathe, Kan. Sample from city supply, August 2, 1906. Comes from Spring Hill, Kan. (ten miles south of Olathe). Average depth, 580 feet. Pressure, 184 pounds.

35. Paola, Kan. City supply. No data. Received August 3, 1906.

36. Burlington, Kan. Collected August 4, 1906, from high-pressure supply-pipe bringing in gas for city supply from wells several miles south.

37. Augusta, Kan. Sample received August 4, 1906. City supply from wells averaging 1440 feet in depth with producing

strata at 1200, 1325 and 1420 feet. Average pressure, about 650 pounds.

38. Marion, Ind. Sample collected by B. A. Kinney, state supervisor of natural gas for Indiana. Received August 25, 1906.

39. Morgantown, W. Va. Collected by B. H. Hite, of West Virginia Agricultural Experiment Station, under direction of Dr. I. C. White, state geologist. From Bowlby well No. 1, ten miles west of Morgantown. Depth, 1800 feet. Pressure, 160 pounds. Collected August 18, 1906.

40. Elmdale, Kan. Collected October 6, 1906. Wells 150 to 154 feet deep. Pressure, 45 pounds. Capacity, nearly one million feet.

41. Eureka, Kan. City supply. Received October 25, 1906. Wells adjoining the city at northeast corner of city limits. Average depth, 375 feet. Average pressure at the wells, 85 pounds. Property of the Eureka Independent Gas Company. Collected by Mr. Sam. Edwards.

42. Eureka, Kan. City supply. Received October 25, 1906. Same as No. 41.

43. Kansas City, Mo. No. 2416 Tracy avenue. Well about 300 feet deep. Very low pressure. Yields only gas enough to light one house.

44. Sheffield, Mo. Composite sample from several shallow wells at the Sheffield Nut and Bolt Works. Initial pressure, about 40 pounds. Aggregate production, about 1600 cubic feet per day. Used to run gas-engine.

45. Pipe-line gas. Collected from mains of Kansas Natural Gas Company at Lawrence, Kan., December 12, 1906. Composite sample, coming from various wells, mostly in Allen and Neosho counties.

46. Jennings, La. Collected by L. Reinecke, assistant geologist on Louisiana Geological Survey, from gas-producing oil-well. Received February, 1907. A little air in sample.

47. Los Angeles, Cal. Collected from gas-producing oil-well by Chas. R. Fletcher, 534 Stimson building, Los Angeles. Sample had some air in it.

51. Pipe-line gas from pipes of Kansas Natural Gas Company at Topeka, Kan. Sample collected from stove-tap in room 79 of the Glenwood hotel, December 22, 1907, at seven A. M.

52. Pipe-line gas from pipes of Kansas Natural Gas Company at Lawrence, Kan., December 23, 1907.

53. Gas from coal-mine, Doranci colliery, near Scranton, Pa. Collected by J. T. Beard, principal of coal-mining division of International Correspondence Schools, December 31, 1907. Analyzed at Lawrence, Kan., January 8, 1908. Gas taken from drill-hole driven six feet into face of coal. Gas escapes from hole at rate of five feet per second.

54. Natural gas from Pierre, S. Dak. Collected by Mr. Doane Robinson, secretary of the State Historical Society, Pierre, S. Dak. Sample had air in it. Only partial analysis made.

DISCUSSION OF RESULTS.

An inspection of table 27 shows that in all cases save one, the Los Angeles gas, helium was found, and it seems very probable that it might have been found in this also if a sufficiently large quantity of gas were taken for analysis. It will be noticed that gas was examined not only from the Kansas field and the adjoining Oklahoma and Missouri fields, which are really continuations of the former, but also representative samples from six other gas-fields at rather widely separated positions in the country—West Virginia, Ohio, Indiana, Louisiana, California and South Dakota, besides one gas from a Pennsylvania coal-mine.

Since our work has been more particularly with the gases of Kansas we may discuss these at length.

It is at once seen that the composition of these gases varies widely, frequently in places which are but a few miles apart. A case of this kind is found in the gases from Arkansas City and from Dexter, towns only about twenty miles apart. (See page 270.) The same phenomenon has been noticed with the oils of Kansas; oil from one side of a town is sometimes of very different composition and properties from that on the other side. This is said to be due to the fact that the porous sandstone which carries the oil and gas is not laid down in continuous layers, but in lenticular masses of irregular size and distribution.

In general, the helium content increases with the nitrogen, although a direct proportionality does not appear to exist. Of course the percentage of both decreases as the percentage of total paraffin hydrocarbons increases, although the ratio of helium to nitrogen may increase.

While there is such a wide variation in the composition of the different gases, there is a marked tendency toward regu-

TABLE No. 27. COMPOSITION OF NATURAL GASES, ARRANGED IN ORDER OF MAGNITUDE OF HELIUM CONTENT.

No.	KANSAS GASES (including adjacent Missouri and Oklahoma gases).	Oxygen. O_2	Carbon dioxid. CO_2	Olefins. C_2H_4 etc.	Carbon monoxid. CO	Methane. CH_4	Ethane. C_2H_6	Total paraffins. $CH_4+C_2H_6$	Hydrogen. H_2	Helium. He	Nitrogen. N_2
1	Dexter	0.20	0.00	.....	0.00	14.85	0.41	15.22	trace	1.84	82.70
6	Dexter (Greenwell well)	0.10	0.00	0.00	0.00	14.33	1.06	15.39	trace	1.64	82.87
41	Eureka, new field	0.10	0.20	0.00	0.00	51.80	0.00	51.80	0.00	1.50	46 40
42	Eureka, town supply	0.50	0.20	0.00	0.00	51.40	0.00	51.40	0.00	1.50	46.40
9	Fredonia	trace	0.61	0.12	0.00	82.25	0.00	82.25	0.00	0.616	16.40
40	Elmdale	0.30	0.15	0.55	0.00	78.60	7.71	86.31	0.00	0.56	12.13
8	Moline	0.00	0.54	.....	0.00	74.10	0.00	74.10	trace	0.51	24.85
36	Burlington	0.00	0.00	0.20	0.00	85.50	3.20	88.70	0.00	0.495	10.60
27	New Albany	0 00	0.20	0.25	0.00	89 10	0.00	89.10	0.12	0.49	9.84
11	Lawrence, deep well	trace	0.92	0.00	0.00	81.40	0.00	81.40	0.00	0.46	17.22
34	Olathe	trace	0.00	0.10	0.00	84.40	0.00	84.40	0.00	0.40	15.10
33	Garnett	trace	0.20	0.16	0.00	94.30	0.36	94.66	0.00	0.37	4.61
4	Eudora	0.31	0.62	0.00	0.00	88.60	0.00	88.60	0.00	0.27	10.20
16	Parsons (Wilson county gas)	trace	0.72	0 00	0.00	91.90	3.37	95.27	0 00	0.27	3.74
31	Buffalo	trace	0.00	0.00	0.11	96.20	0.78	96.98	0.18	0.27	2.46
28	Altoona	0.00	0.92	0.00	0.00	92.00	2.85	94.85	0.00	0.263	3.97
37	Augusta	0.00	0.00	0.77	0.00	79.10	7.44	86.54	0.00	0.25	12.44
25	Chanute	0 10	0.00	0.00	0.00	94.70	0.00	94.70	0.00	0.24	4.96
20	Moran	0 20	0.30	0.35	0.20	92.00	0.00	92.00	0.39	0.214	6 35
23	Peru	0 10	0.51	0.51	0.00	81.70	7.60	89.30	0 00	0.19	9.39
7	Iola	0 23	0.00	0.00	0.00	94.50	0.00	94.50	trace	0.183	5.08
3	Lawrence pipe-line, May 16, 1906	trace	0.20	.....	0.00	98.06	0.00	98.06	trace	0.17	1.57
2	Pipe-line, October 23, 1905	0.12	0.00	.....	0.00	98.00	0.00	98.00	0.00	.....	1.88

45	Pipe-line, December 12, 1906	0.24	1.94	0.00	0.00	94.30	0.75	95.05	0.00	0.17	2.60
17	Arkansas City	0.20	0.10	0.10	0.00	81.10	11.95	93.05	0.00	0.159	6.39
32	Blackwell, Okla.	0.00	0.00	0.61	0.00	83.40	10.31	93.71	0.33	0.16	5.19
26	Humboldt	0.10	0.00	0.81	0.00	94.00	1.97	95.97	0.00	0.14	2.98
21	Iola	0.40	0.70	0.00	0.30	91.50	0.00	91.50	0.00	0.132	6.97
12	Erie	0.22	0.33	0.30	0.00	90.30	4.26	94.56	0.00	0.13	4.45
10*	Neodesha	.....	.....	.....	.....	.....	.....	.....	.....	0.106	.....
15	Bonner Springs	0.10	0.00	0.00	0.00	97.18	0.00	97.18	0.25	0.104	2.36
18	Altamont pipe-line, Liberty and Coffeyville,	0.00	0.92	0.61	0.00	95.70	0.00	95.70	0.00	0.08	2.69
22	Caney	0.15	0.81	0.10	0.00	92.40	0.00	92.40	0.00	0.08	6.46
44	Sheffield, Mo	0.20	0.83	0.50	0.10	92.90	0.00	92.90	0.00	0.041	5.43
43	Kansas City, Mo., 2416 Tracy avenue	0.10	0.60	1.20	0.20	87.20	7.03	94.23	0.00	0.013	3.65
35	Paola	0.40	0.70	0.00	0.00	98.00	0.00	98.00	0.00	0.0093	0.88
14*	Bartlesville, I. T.	.....	.....	.....	.....	.....	.....	.....	.....	†	.....
51	Topeka pipe-line, December 22, 1907	0.20	1.53	0.00	0.00	94.56	0.00	94.56	0.00	.....	3.71
52	Lawrence pipe-line, December 23, 1907	trace	1.85	0.00	0.00	94.47	0.00	94.47	0.00	.....	3.68
	GASES FROM OTHER FIELDS.										
24	Butler, Ohio	0.05	0.00	0.40	0.00	70.00	16.75	86.75	0.27	0.15	12.38
38	Marion, Ind.	0.00	0.73	0.86	0.00	77.40	14.18	91.58	0.00	0.167	6.66
39	Morgantown, W. Va.	0.00	0.24	0.65	0.00	88.10	7.37	95.47	0.25	0.09	3.60
46	Jennings, La. (some air in sample)	1.81	1.80	0.80	0.40	88.40	1.03	89.43	.....	trace	5.76
47	Los Angeles, Cal. (some air in sample)	2.86	6.68	0.20	0.25	83.70	0.00	83.70	.....	0.00	6.31
53	Gas from coal-mine, Scranton, Pa.	0.92	1.06	0.39	0.13	94.2	0.00	94.20	0.00	trace	3.31
54	Pierre, S. Dak.	3.19	1.14	0.25	0.00	73.2	0.00	73.20	.....	trace	21.7
	Same, corrected to air-free gas.	0.00	1.35	0.29	0.00	86.50	0.00	86.50	.....	trace	11.86

*No complete analysis. †Helium present but not determined.

percentage of helium and of total paraffin hydrocarbons, along lines running across the state from northeast to southwest, as may be seen from the two accompanying maps.

DISTRIBUTION OF HELIUM
IN KANSAS NATURAL GAS.

FIG. 7.

Figure 7 shows these lines of nearly equal helium content and figure 8 shows the lines of nearly equal paraffin content. These lines, which may be called *isohelium* and *isoparaffin* lines, are suggestively similar to the lines showing the outcrop of the various geological strata in eastern Kansas.[163]

The explanation of this regularity of distribution is undoubt-

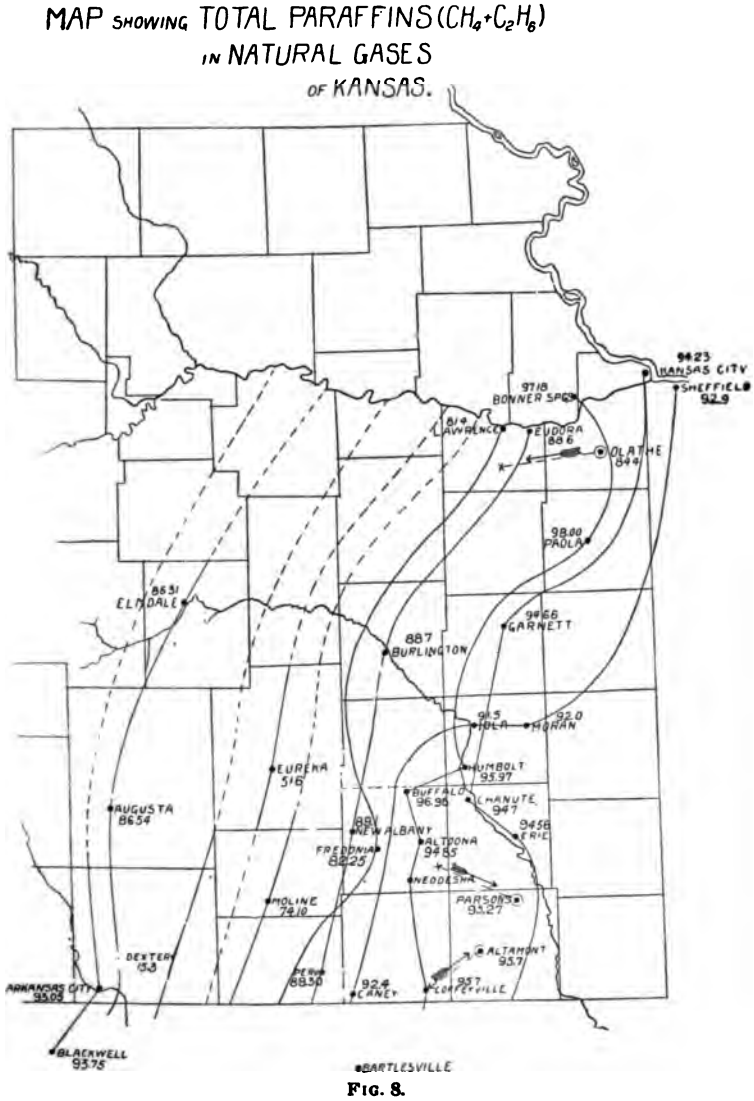

FIG. 8.

163. A map showing the latter may be found in vol. III of the Reports of the University Geological Survey of Kansas; plates 7 and 8, p. 106.

edly to be found in the arrangement of the strata, and the few marked exceptions to this regularity are explainable by the presence of unusual formations at the points where the exceptions occur. But this is a matter that is more in the province of the geologist than in that of the chemist.

The fact that our analyses have shown helium in all but one of the gases examined from various parts of the United States, together with numerous reports of helium having been found in the gases from mineral waters,[164] leads us to believe that helium may be found in greater or less quantities in all gases issuing from the earth, and that, like many other so-called rare elements, it is really of very wide distribution.

Since Ramsey and Soddy's demonstration of the transformation of radium emanation into helium[165] and Strutt's work[166] showing the very wide distribution of minute percentages of radium in various rocks and soils, it would, of course, occur to every one that perhaps the helium in natural gases came from the transformation of the emanation derived from the radium. While the percentage of radium is exceedingly small, the aggregate amount is sufficient, granting the transformation, to account for all the helium, provided that sufficient time is given. Since Ramsey[167] has shown that radium emanation in the presence of water is transformed into neon, and in the presence of copper salts into argon, these latter gases present in natural gas may have had their origin in radium as well as the helium.

If the helium comes from the radium, the percentage of helium in the gas should be proportional to the age of the gas, the radium content of the contributing strata, and inversely proportional to the total quantity of gas. Of course, many other factors would enter into the consideration of this question, such as the rate of diffusion of helium and the accompanying gases, and the fact that the age of the gas cannot always be judged by the age of the strata in which it is found, its position being

164. Rayleigh, Chem. News, *72*, 223 (1895); *73*, 247 (1896); Zentralblatt, *1895*, [2] 1112; *1896*, [2] 147. H. Kayser, Chem. News, *72*, 89 (1895); Chem.-Ztg., *19*, 1549 (1905). Bouchard and Troost, Compt. rend., *121*, 392 (1895); Zentralblatt, *1895*, [2] 710. Moureu, Compt. rend., *121*, 819 (1895); *135*, 1335 (1902). F. Pesendorfer, Chem.-Ztg., *29*, 359 (1905). R. Nasini, Attl accad. Lincei (5) *13*, 1, 217, 367 (1904); Zentralblatt, *1904*, [1] 1190; [2] 77. Frytz and Thorkelsson. Kgl. Danske Videnski Selsk Forh. *1905*, 317; Zentralblatt, *1905*, [2] 1570. Ewers, Physik. Z., *7*, 224 (1906); Zentralblatt, *1906*, [1] 1319. Moureu and Blquard, Compt. rend., *143*, 795 (1906); Zentralblatt, *1907*, [1] 500. Moureu, Compt. rend., *142*, 1155 (1906); Zentralblatt, *1906*, [2] 156.

165. Pr. Roy. Soc. London, *72*, 204 (1903); *73*, 346 (1904).

166. Chem. News, *93*, 235 (1906).

167. Jour. of Chem. Soc., CXI, 1593-1606. 1907.

largely determined by the presence of a sufficiently porous stratum in which it could be stored, and of a difficultly penetrable cap over this stratum.

All of these things make it very difficult to test this hypothesis quantitatively, and at present we wish only to state our belief in its possibility.

CONCLUSIONS.

In this paper the results of the examination of forty-six samples of natural gas from several widely separated parts of the country are given. These lead to the following conclusions:

First.—That helium is present in all cases except possibly one. It is inferred from this that it is present in all or nearly all of the gases issuing from the earth.

Second.—The helium content of the gas tends to increase as the nitrogen increases, though no direct relation is observed.

Third.—In Kansas, lines of isohelium and isoparaffin content can be traced across the state, and these follow approximately the lines of outcrop of the various geological strata.

Fourth.—A very wide variation in composition is noted in the gases examined; hydrocarbons varying from 15 per cent. to 98 per cent., and helium from a trace up to 1.84 per cent.

The Heating Power of Kansas Gas.

A subject of great practical importance to the consumer of gas, as well as of theoretical interest to the chemist, is its heating power or calorific efficiency. This, in the case of gaseous fuels, is expressed either in terms of British thermal units per cubic foot of gas, or of kilogram calories (large calories) per cubic meter. A British thermal unit (B. T. U.) is the amount of heat necessary to raise one pound of water one degree Fahrenheit. A kilogram calorie is the amount of heat required to raise one kilogram of water one degree Centigrade.

There are two ways of obtaining some idea of the heating power of a fuel.

One of these is to calculate the theoretical heat value on the basis of the chemical analysis. This is done by multiplying the percentage of each separate constituent of the fuel by the quantity of heat (in calories or B. T. U.) which may be obtained by burning a unit quantity of the pure substance under proper conditions. The several values thus obtained give, when added together, the heating value of the whole fuel. The

values thus obtained by calculation from a volumetric analysis of a gas are subject to grave errors, which make them, at best, little better than mere approximations. It is so difficult to determine accurately the relative quantities of methane, ethane and higher hydrocarbons (see discussion of this point on page 278) and there is such a large difference in the heating value of these substances that a relatively small error in the analysis will produce a large error in the calculated heat value, and thus vitiate the results obtained. In general, it may be said that a calculated heating value of a gas is only as reliable as the values for the amounts of the separate hydrocarbons calculated from the analytical explosion data.

The other method of obtaining the heating value is to actually measure, in a properly devised calorimeter, the quantity of heat given off when a known weight or volume of the fuel is burned under standard conditions.

For gases this is done by means of a gas-calorimeter. There have been devised several such instruments, but all possess somewhat similar construction and are based upon practically the same principles. Briefly stated, these are as follows: A carefully measured volume of gas at uniform and determined pressure and temperature is burned in the instrument in such a way that all of the heat given off during the combustion is transmitted to water, which is flowing under a constant head through the instrument. The rise of temperature of the water during its passage, multiplied by the weight of water passed through during the time of burning a unit volume of the gas, gives the amount of heat available from the combustion of the given volume of gas at the prevailing temperature and pressure, the water produced in the combustion being largely condensed to liquid.

If this value is to be compared with the heat value calculated from the analysis of the gas, it is necessary to subtract from it the heat given off by the condensation of the water formed in the combustion of the gas. Since the theoretical calculation is based upon volumes of gas measured at standard conditions of temperature and pressure, 0° Centigrade, and 760 millimeters pressure, the value determined by the calorimeter measurement must also be reduced to the same conditions.

Many of the published results for determination of heat values do not state whether or not this correction has been made. We judge from the appearance of some of them that it

has not. The apparent heat value in these cases is of course higher than the corrected value would be.

The instrument used in the determinations here presented was a Sargent automatic gas-calorimeter, which is so arranged that one operator can run a complete test on a gas without assistance. The gas was measured in a wet meter registering thousandths of a cubic foot and having a capacity of one-tenth cubic foot per revolution. Each complete revolution of the needle caused the closing of an electric circuit which automatically switched the flow of water from the calorimeter from one weighing vessel to another. At each change the weight of water was determined and readings made on the thermometers at the inlet and outlet of the water.

During each series of measurements made on the gas, a sample of the gas was taken for analysis. The results given are averages for the heat value and for the analytical results.

The determination of heat values was undertaken too late to permit any extended series of such measurements to be made. The difficulty of transportation of the apparatus and of securing sufficiently adequate places to work at the wells made it necessary that the work be done in the University chemical laboratory. It was found, also, that a supply of gas adequate for an extended run on a gas could hardly be carried in one collecting cylinder, so that determinations were limited to gases that could be gotten at the laboratory in goodly quantity.

This was found in the gas supplied to the city of Lawrence by the pipe-line of the Kansas Natural Gas Company. Coming as it does from a large number of wells scattered over a considerable area in the southern Kansas field, this gas is a composite sample that represents a whole field rather than any single well or set of wells. It is subject to some variation in composition, as will be seen from the several analyses that have been made upon it from time to time ever since it was first turned into the pipes. This variation, however, has not been excessive, considering the wide area from which the gas has come, and the results obtained may be taken as somewhat representative of gas of this approximate composition. It will not, however, be at all representative of the heat value of gas from the entire state. In view of the wide variations in composition of the Kansas gases, as shown in the analyses, table 27, p. 270, this would be impossible, and we hope that no one will get such an impression.

EXPERIMENTAL RESULTS.

Heat value of gas from pipes of Kansas Natural Gas Company. Samples taken from supply-pipes in chemical laboratory of the University of Kansas. Analyses and calculations of heating values from analyses made by D. F. McFarland. Calorimeter measurements made by H. G. Elledge.

Three separate series of determinations were made, with the following results:

Results calculated to 760 millimeters pressure and 0° Centigrade temperature, and corrected for heat of condensation of water formed in combustion:

Series.	Date.	B. T. U. per cu. ft.
1	July 10, 1908, 11 A. M.	936
2	July 10, 1908, 5 P. M.	930
3	July 11, 1908, 5 P. M.	924
	Average for three series	930

Analysis of sample No. 2 gave the following composition:

TABLE No. 28.

Oxygen	0.25
Carbon dioxid	0.81
Olefins	0.38
Carbon monoxid	0.81
Methane	93.50
Ethane	0.00
Hydrogen	0.00
Nitrogen	4.25
Total	100.00

In obtaining the theoretical heating value of the gas, the values given for the individual constituents in Richard's Metallurgical Calculations[168] were made use of. Selecting from the analysis those substances which have fuel value, the number of parts by weight of each substance was multiplied by its heat value.

	Pts. in 1 cu. ft.	Heat value.	B. T. U. Effect in 1 cu. ft.
Olefins	.0038	1,627	6.18
Carbon monoxid	.0081	344	2.78
Hydrogen	.0000	293.5	0.00
Ethane	.0000	1,728	0.00
Methane	.9350	966	903.21
Total heat value			912.17

Dividing this value by 0.11233 we get 8120.5 kilogram calories per cubic meter.

The agreement between this calculated value and that actually determined is not bad, considering the many sources of

168. Vol. I, pp. 81, 82.

error in the calculated results. Both reveal the fact that the gas, which is about an average good gas for the Kansas field, is of high fuel value.

IMPORTANCE OF CALORIMETRIC DETERMINATIONS.

The principal uses to which natural gas is put at present are those which involve the heating effect of the gas. This is even true in the use of the gas for lighting purposes, since it is the heating of a mantle of rare earths which produces incandescence and gives the light. Dilution of the gas with incombustible substances will, of course, lower the heating value, and the gas is not worth so much to the consumer. The presence of nitrogen lowers the heating effect in this way. Not only does the nitrogen not burn itself, but it decreases the heat effect of the other constituents of the gas which really are fuels. The amount of heat given up to any surface hotter than the surrounding air decreases with the dilution of the gas by nitrogen, by an amount which is equal to the weight of the nitrogen, times the difference in temperature, times the specific heat of nitrogen. This effect becomes of importance in gases like the Dexter supply, which contains nearly 83 per cent. of nitrogen; Eureka gas, which has 46.4 per cent. nitrogen; the gas from Moline, which contains nearly 25 per cent. of nitrogen, and some others of the state which are relatively high in nitrogen. These obviously cannot have as high heat value as other gases in the state which are lower in nitrogen and correspondingly high in methane and ethane.

Natural gas is usually sold by the thousand cubic feet, a fixed price being made for this unit. The ordinary user does not discriminate between gas of high fuel value and gas of lower fuel value. He does not appreciate the fact that in buying a gas low in fuel value at the same rate as that paid for the gas of high fuel value he is paying a much higher price for the amount of heat obtained. It will be easily seen that about twice as much of a gas like that from Eureka, which is nearly half nitrogen, will be required to produce the same amount of heat in a stove that is produced by a gas of high methane content, such as the gas from Iola or Chanute, which has only about 5 per cent. of nitrogen. This nearly doubles the actual cost to the consumer.

A short calculation will show the difference in the cost of heat units to consumers of Eureka gas at 30 cents per thousand and to consumers of Iola gas at 25 cents per thousand.

Most franchises to gas companies do not say anything about the heat values of the gas. So long as "natural gas" is furnished, the stated sum may be charged per thousand cubic feet. Now, if, as we have seen, this "natural gas" may vary widely in composition and in heat value and therefore vary in its value to the user, it would seem better that the gas should be sold on the basis of the heat value as determined by actual calorimetric measurement.

It is just as important that calorimetric control be made on the gas furnished to a community as that chemical control be made of the water supply furnished to the community. We would suggest, therefore, the advisability of such control under some regularly constituted authority of the state in the same manner as the control of water and food supplies by the State Board of Health. Careful attention paid to this matter would doubtless save to the gas-consumers of the state an amount of money vastly in excess of its cost.

SECTION IV.

GENERAL DISCUSSION.

1. Scarcity of reliable gas analyses.
   - *a.* Insufficient survey of gas-producing areas.
   - *b.* Sources of error in analyses.
   - *c.* Variation in gas from different parts of same field.
2. Variation in composition of gas from same source.
   - *a.* Evidence. Phillip's work.
   - *b.* Possible explanation of variation.
   - *c.* Desirability of further investigation.
3. The uses of natural gas.
   - *a.* As fuel.
   - *b.* In chemical manufacture.
     - Hydrocarbon gases.
     - Nitrogenous gases. Calcium cyanamid, etc.
     - Gases high in helium, etc.
   - *c.* Need for intelligent investigation of new uses.

General Discussion.

In this report we have given nearly all the gas analyses which we have been able to find, and while there are undoubtedly many which have been overlooked in our search we believe that the most important ones are here recorded. The number of analyses of gases from wells which are commercially productive is surprisingly small, and many of them are of but little value, owing to defective methods of analysis. These few analyses, both good and bad, have been quoted time and again. A few analyses have been taken as representing the composition of gas over large areas. This is a somewhat dangerous thing to do. It is perhaps more nearly justified for

some producing areas than for others. If the area is of such a character that the gas is really from one large source, then the gases would mix until they were of a uniform composition throughout. If this is the case, the well-pressure when closed down should be the same on the whole area, and should gradually decrease in all wells—those which are not being drawn upon as well as those which are producing. If the wells do not show these characteristics, then they must draw their supplies from separate and isolated sources, and under these circumstances the gas from one may resemble that from another very closely or it may differ widely. The gas-producing areas in Kansas are very evidently isolated from one another, and the gases which they produce differ radically in their composition. A good example of this is observed in the gases from Arkansas City and from Dexter, Kan. These are apparently both from the same geological horizon and the fields are only some twenty miles apart, but the gases could hardly differ more from one another than they do if they came from the opposite sides of the earth. We suspect that the same sort of difference might be found in some of the other gas-fields of the United States if sufficiently extended explorations were taken up. As a rule, the analyses which we have recorded from other gas-fields have been from rather small areas, usually near the center of the producing field. The advantage of a more extended series of analyses, covering all parts of the producing field, is readily seen.

Many of the reported variations in composition are more apparent than real. This is largely due to errors in interpretation of analytical data.

As stated above, many of the published analyses are of doubtful value. As such we would class those showing any great amount of hydrogen, especially where the latter is calculated from the explosion data and the gases are measured over water, as is usually the case when the more modern forms of gas-analytical apparatus are used. Many of the older analyses, made by Bunsen's methods, such as those by St. Claire Deville, Fouqué and others, which show in a few cases the presence of hydrogen, are worthy of considerable confidence. But the modern explosion pipettes differ materially from the long, narrow eudiometers of Bunsen, and the temperature reached during the explosion is undoubtedly much higher in the former apparatus than in the latter. The natural result is

that a very sensible amount of combustion of nitrogen often takes place under conditions as to mixture, etc., which would have given nearly perfect results with the Bunsen apparatus.

Another very fruitful source of error is the rather rapid absorption of carbon dioxid in the water over which the gases are measured after the explosion. This increases the apparent contraction on explosion and decreases the absorption by potassium hydroxid, and so produces a fictitious appearance of hydrogen. This is the source, without much doubt, of much of the hydrogen which is reported in gas analyses. That hydrogen is never present in natural gas we would not like to assert; in fact, we believe that it often is present, but only in very small quantities. Consequently, we regard with some suspicion an analysis of a gas from an ordinary producing gas-well which shows more than one per cent. of hydrogen. To this class belong the much-quoted analyses by Mr. S. A. Ford (see table 10, p. 245), which have been often referred to as showing that gas from a certain well may vary within wide limits. Apparently they showed that the gas analyzed rapidly fell off in methane and increased in hydrogen, the latter changing from 10 per cent. to 36 per cent. in about six weeks. His results, as we see them, would point rather to the gradual accumulation of potassium hydroxid in his measuring apparatus, which would greatly accentuate the errors noted above. This is, then, a case of apparent rather than real variation.

The calculation of methane and ethane from the explosion data is also open to some question. We have made the calculation for the gases which we have analyzed, but we do not regard the results as possessing any very high accuracy so far as they represent the actual quantities of the individual paraffins. In order to make this calculation, the contraction on explosion, the carbon dioxid formed during the explosion, and the oxygen used up in burning the gas, were determined. Between these factors three equations may be set up from which the methane may be calculated and three more for the ethane. (See page 258.) Each of these equations involves two of the factors. They often yield results which differ materially from one another, and this difference is due to apparently unavoidable errors in the data from which they were calculated. In every case the nitrogenous residue from the gas was actually determined, and this furnished a valuable check on the accuracy of the calculated values. It was usually found that the

mean of the values for the different equations agreed well with this residual nitrogen as actually determined. Consequently, we believe that the figures which we have given in our table of results are not far from correct.

That actual variation in the composition of the gas from a single well may take place seems to be shown by the determination of nitrogen by Phillips in the gas from certain wells, the samples being taken from time to time for a considerable period.[169] For example, the nitrogen content of the Shields well, fourteen miles west of Pittsburg, ran as follows:

	Percentage of nitrogen.	
August 5, 1896	1.25	1.26
February 5, 1897	2.67	2.68
April 6, 1897	1.79	1.80
April 20, 1897	1.85	1.85
June 1, 1898	1.10	1.10

These fluctuations are evidently much greater than the experimental error and one must conclude that the variations are real. An explanation of the cause of these changes is not easy. Some have suggested that it is due to the gas being liquefied by pressure and then gradually boiling off the more volatile constituents. This certainly cannot be the cause, because the critical temperature of methane, above which temperature it cannot be liquefied by any pressure, however great, is —81.8° Centigrade, while the temperature of the gas in the earth is of course much higher than this.

In case the gas comes from several strata, separated from each other by impervious layers, it is not unlikely that the gas from the various strata will differ in composition and also that the relative proportion of the outflowing gases from each stratum will vary with the water condition and the demand upon the well. It is the rule that the deeper the point at which the gas is struck the higher will be its pressure. If two gas-sands are passed through by the well they will probably have different pressures, and if the well is working to something like its full capacity both sands will be contributing gas; but if the flow is reduced until the well-pressure is as high or higher than that of the weaker sand, only the stronger sand will furnish the gas. If there is a difference in composition of the gas from the two sands it is very obvious that the composition of the gas will vary with the flow. If the well is so far closed down that the pressure rises higher than that of the

169. Proc. Am. Acad., *34*, 78, 1898.

weaker sand then the latter will act as a storage reservoir for the gas from the stronger, giving it up again with increased demands upon the well, thereby producing extremely complicated variations in the composition of the gas.

Prof. I. C. White[170] describes a well which passed through three gas-sands, and which was expected to show when closed a pressure of 1500 pounds. Instead, the pressure rose to only 650 pounds, corresponding to about that of one of its higher sands. After standing closed for a year the pressure was so great as to blow up in several places a two-inch pipe-line into which it was turned, so that the pressure must have reached the point first expected, and the low pressure at the start must have been due to the storage in the weaker sand. Other similar cases are reported by Doctor White (*loc. cit.*).

Another source of variation in the composition of natural gases is to be looked for in the diffusion phenomena taking place during the passage of the gas from remote rocks to the well. As is well known, the lighter gases diffuse more rapidly than the heavier. Here again, alterations in the flow would change the composition somewhat. This point has been discussed by Doctor Chance.[171]

It is a matter of considerable importance to a community which uses as much natural gas as Kansas does to know whether or not the supply from the wells is changing materially in composition. We have seen the relation between composition and heat value, and since this heat value is the important thing to users of the gas any marked change would be of interest to the user. It is hoped that a complete investigation can be made of the Kansas gas-supplies in the future to determine whether or not such a variation is taking place.

THE USES OF NATURAL GAS.

The use of natural gas as a fuel is of course so familiar that there is no need to speak of it at length here. To a chemist, it would seem better, since it is a good starting-point for the manufacture of various chemical substances, to use it for this purpose rather than as a combustible.

The main constituent of ordinary natural gas is, of course, methane (CH_4). The chemical substances which may be derived from this compound by various chemical reactions are

170. W. Va. Geol. Surv., vol. 1*a*, 71, 1906.

171. Proc. Eng. Club, Philadelphia, 5, 369 (1886).

almost without number, and comprise a large and important part of the world of organic chemistry. While it is very difficult to cause the elements carbon and hydrogen to unite, when they are once combined their compounds undergo further changes with comparative ease. It would seem a very worthy use for natural gas, with its high percentage of methane, to take it as the starting-point in the preparation of other more important compounds.

For example, methane may be so burned that more than 22 per cent. of the gas is changed into formaldehyde (CH_2O), which is well known as a valuable antiseptic, greatly used, especially for purposes of fumigation. Methane is rather resistant to chemical attack, and before it is utilized in a chemical way much work must be expended on the investigation of the problem, but the rewards for success in such research are quite enough to repay every effort.

There are possibilities even for the use of gases that are not available for fuel or for such other purposes as have been indicated above.

Prof. R. K. Duncan, of the University of Kansas, has found that the Dexter gas, which is very rich in nitrogen, will yield calcium cyanamid ($CaCN_2$) when passed over calcium carbid (CaC_2) at a high temperature. The calcium cyanamid is a very good fertilizer, and its manufacture from those gases which are not serviceable as fuels would be an admirable use for what seems to be otherwise nearly valueless substances, were it not for the excessive cost of calcium carbid, which in this country is in the hands of a monopoly. In Europe, where the carbid is cheaper, large quantities of calcium cyanamid are now made and used, getting the nitrogen from the air by a fairly expensive process.

Investigations of the character of the above would undoubtedly lead to important uses of natural gas in fields where its application would not be blocked by monopoly.

The use of natural gas as a source for the rarer gases, helium, argon, neon, etc., has already been mentioned (p. 236). and considerable quantities of helium and neon have been extracted from this source. The uses found for them have been largely experimental.

SECTION V.

ANALYSES OF EUROPEAN NATURAL GASES.

1. Gases from volcanoes and geysers.
2. Gases from springs, etc.
3. Gases from salt-mines and salt-wells.
4. Regular natural gases.
5. Gases from borings.
6. Gases from rivers, lakes, marshes, etc.
7. Mine gases.
8. Gases occluded in coal.

European Analyses of Natural Gases.

In the following section a considerable number of analyses of natural gases from a wide variety of localities and sources in Europe are given. These have been collected in the course of several months' work, and are given for purposes of comparison with the Kansas gases, as well as to afford a larger collection of such data than may ordinarily be found. We hope that they may be found of value.

No guarantee can be made of the absolute correctness of the transcription of either the references or the analytical data. Mistakes are very apt to creep in in copying. Much effort has, however, been expended in an endeavor to prevent such errors. The analyses are arranged in tables immediately following the references. With each reference is a number, shown at the side of the page, by means of which the corresponding analysis or set of analyses may be found in the tables. The year in which the analysis was made or published is also shown with this number.

GASES FROM VOLCANOES AND GEYSERS.

Bunsen 1851

TABLE No. 29.

FUMAROLE GASES FROM ICELAND.

Bunsen.[172]

	I	II	III
	Fumaroles from great Hecla crater.		Fumaroles from lava stream of 1845.
Nitrogen	81.81	82.58	78.90
Oxygen	14.21	16.86	20.09
Carbon dioxid	2.44	0.56	1.01
Hydrogen sulfid	0.00	0.00	0.00
Sulfur dioxid	1.54	0.00	0.00
Carbon monoxid	0 00	0.00	0.00
Hydrocarbons	0.00	0.00	0.00
Hydrochloric acid	Undetermined.		
	100.00	100.00	100.00

172. Pogg. Ann. 58, 197. Jahresbericht (1851) 854.

Bunsen 1851

SULFUR FUMAROLES, ICELAND.[173]

Analyses by Bunsen.

	a	b	c	d	e	f	fa
	Krisuvik.	Near Krisuvik	Vapor stream from Mud Kettle.	Krisuvik.	Krisuvik.	Reykja-lidk.	Great Geyser.
Nitrogen	1.67	0.69	0.50	1.80	1.44	0.72	84.11
Carbon dioxid	87.43	88.24	79.07	88.54	86.92	30.00	8.92
Hydrogen sulfid	6.60	6.97	15.71	1.79	3.28	24.12	0.38
Hydrogen	4.30	4.10	4.72	7.87	8.36	25.14	6.59
Carbon monoxid	.....	.....	.....	.....	.....	.....	.....
Oxygen	.....	.....	.....	.....	.....	.....	.....
Methane	.....	.....	.....	.....	.....	.....	.....
	100.00	100.00	100.00	100.00	100.00	*79.98	100.00

Vesuvius 28

TABLE No. 30.

GASES FROM CLEFTS IN LAVA OF VESUVIUS.[174]

	1	2	3	3a
Sulfur dioxid	0 64	.....	0 03	0 07
Oxygen	20 00	20 70	20 50	20.77
Nitrogen	78.36	79 30	79.47	79.16
	99.00	100 00	100 00	100.00

Cerboli, Italy, 1858, 29

TABLE No. 31.

GASES FROM MOUNT CERBOLI AND VICINITY.[175]

St. Clair Deville and F. Leblanc.

	A	B	B1	C
Hydrogen sulfid	4 10	3 70	85.10	N_2 43 35
Carbon dioxid	91.60	90 70		
Oxygen	0.00	0 00	2 70	H_2 28 56
Nitrogen and combustible gases	4.30	5.60	12.20	CH_4 28.09
	100.00	100 00	100.00	100 00

29a *St. Clair Deville.* Gases from Vesuvius.[176]

CO_2	59.53
O_2	0 00
Combustible gases $+ N_2$	40.47
	100.00

30 *St. Clair Deville and others.* Gases from Vesuvius and other volcanic localities.[177]

31 Also.[178]

173. Jahresbericht, 1851, p. 856, table on p. 849.

* Does not add up to 100.

174. Jahresbericht, 1857, 713.

175. Jahresbericht (1858), 791-793.

176. Compt. Rendus. 53, 1231. Jahresbericht, 1861, 1116.

177. Jahresbericht, 1862, pp. 806-809. 178. Jahresbericht, 1863, pp. 880-881.

32 *Fouqué.* Gases from fumaroles and other volcanic sources in southern Italy.[179]

33 *Fouqué.* Gases from volcanic sources on island of Santorin, Greece (1866).[180]

37 *O. Silvestri.* Fumarole gases from Mt. Ætna (1865).[181]

34 *S. de Luca.* Analyses of gaseous exhalations from solfataras at Puzzuoli, Italy. (Bay of Naples).[182]

75 1902 *Henri Moissan.* Presence of argon, carbon monoxid and hydrocarbons in the gases from the fumaroles of Mt. Pelee, Martinique.[183]

Samples collected between eruptions of May 8 and August 30, 1902. Temperature of the gases at exit, about 400° C. Table 32.

79 1904 *Henri Moissan.* Presence of argon in gases from fumaroles of Guadeloupe. (*a*) Sample from Fumarole du Nord. (*b*) From Fumarole Napoleon.[184] Table 32.

TABLE No. 32.

GASES FROM VOLCANIC SOURCES.

Recent Analyses.

CONSTITUENTS.	75	79*a*	79*b*
	Mt. Pelee, Martinique.	Fumaroles Guadeloupe du Nord.	Fumaroles Guadeloupe Napoleon.
Methane	5.46	.....	0.00
Ethane	.....	.....	0.00
Propane	.....	.....	0.00
Carbon dioxid	15.38	52.80	69 50
Carbon monoxid	1.60	.....	0.00
Olefins (ethylene)	0 00	.....	0.00
Hydrogen	8.12	.....	0.00
Oxygen	13 67	7 50	2.70
Nitrogen	54 94	36 07	22.32
Argon	0 71	0.73	0.68
Helium, etc	0.00	.....	.....
Hydrogen sulfid	0.00	2.70	4.50
Illuminating hydrocarbon	0.00	.....	.....
Totals	99.88	99.80	99.70

179. Jahresbericht, 1865, pp. 926-927.

180. Compt. Rendus, 64, 184. Jahresbericht, 1867, 1031. Numerous analyses.

181. Jahresbericht, 1869, 1278. Two analyses.

182. Ann. Chim. Phys. 4, 26, 289. Jahresbericht, 1872, 1176-1179.

183. Compt. Rendus, 135, 1085-1088, (1902).

184. Compt. Rendus, 138, 936-938. 1904. Jour. of Chem. Soc. A., II, 415, 1904.

GASES FROM SPRINGS, ETC.

1851
Germany

TABLE No. 33.

ANALYSES OF GASES FROM GERMAN SPRING WATERS.[185]

Robert Bunsen.

	Gases from Acchen Hot Springs.						Gases diffused in Nenndorf sulfur water.		
	l	*m*	*n*	*o*	*p*	*q*	*r*	*s*	*t*
	Gas from Kaiserquelle. Free gas.....	Gas diffused in water of Kaiserquelle.....	Gas from Cornelius quelle. Free gas.....	Gas diffused in water of Cornelius quelle..	Quirinus bad.....	Rosenquelle.....	Trinkquelle.....	Quelle unter dem Gewölbe.	Badequelle.....
Nitrogen.....	66.98	9.00	81.68	7.79	6.41	9.14	17.30	19.91	23.91
Carbon dioxid.....	30.89	89.40	17.60	92.21	93.25	90.31	69.38	68.29	72.63
Hydrogen sulfid.....	0.31	.....	.....	.....	.....	.....	11.86	11.72	3.29
Hydrogen.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Carbon monoxid.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Oxygen.....	.....	1.23	.....	.....	0.08	.....	.....	.....	.....
Marsh-gas.....	1.82	0.37	0.72	.....	0.26	0.55	1.46	0.28	0.17
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

49 1900 *Bourcet, Paul.* Gas from a mineral spring of Joulie near Dôle, Jura, France.[186] Table 34.

20 1900 *R. Nasini* and *F. Anderlini.* Gases from water of Royal Salinen and Bäder at Salsomaggiore, Italy.[187] The results are stated in cubic centimeters per liter. We have calculated these to per cent. of total gaseous contents and have so stated them in table 34.

33 *F. Parmentier* and *A. Hurion.* Gases given off by springs at Mont-Dore, France.[188] Table 34.

55 *Abich.* Analysis of gas escaping from hot sulfur springs at Michalow, in Caucasus mountains.[189] Table 34.

185. Pogg. Ann. 83, 197. Jahresbericht, 1851, 849.

186. Bull. Soc. Chim. Paris, (3) 23, 144 (1900).

187. Centralblatt. 1900, I—1239.

188. Jour. Chem. Soc. Abstracts. 1900. Centralblatt, 1900, I—1239. Compt. Rendus, 130, 1190-'91.

189. Bull. Acad. Sci. Imp. St. Petersburg. (2) XI, pp. 397-412 (1867).

TABLE No. 34.

GASES IN MINERAL SPRINGS.

	49	20	53	55
	Joulie Dole, France.	Salso-maggiore, Italy.	Mont-Dore, France.	Michailow Caucasus, Russia.
Carbon dioxid	29.35	41.25	99.50	13.107
Oxygen	7.32	0.35	.....	0.130
Nitrogen	61.16	4.50	0.49	40.397
Methane	2.17	44.35	.....	46.144
Hydrogen sulfid	race	.....	.....	0.222
Ethane	.....	8.60	.....	.....
Heavy hydrocarbons	.....	0.95	.....	.....
Argon	.....	.....	0.01	.....
Hydrogen	.....	.....	.....	.....
	0.00	100.00	100.00	100.00

18 1897 *Ch. Bouchard* and *Desg* Gas from mineral water of Bagnoles, de l'Orme.[190]

19 1896 *M. von Breukeleveen.* Gas from spring at Enkhuizen, North Holland.[191]

77 1902 *Chas. Moreau.* ne s s of mineral gas.[192] Five springs in the Pyrenees y ning argon as follows: Per cent. by volume, .09, 1.6, 1.. ll contain nitrogen, carbon dioxid, oxygen, etc. One l nd traces of some other gas of the argon group.

78 1902 *Henri Moissan.* Presence of argon in the gas from Borden Spring at Luchon and the presence of free sulfur in the sulfur waters of the Grotto and the vapors used for inhalation.[193]

16 1898 *R. Nasini, Anderlini* and *Salvadori.* Gases from the Abano Springs and the Boracic Suffoni of Tuscany and the combustible gas from the Bolognian Apennines.[194]

(*a*) Gas with hot mineral water at Monte Irone in Abano. Two per cent. of the unabsorbed residue is argon and helium.

(*b*) Combustible gas from mineral waters of the Poretta Baths.

190. Compt. Rendus, 123—969-970. Centralblatt, 1897, I, 257.

191. Rec. trav. chim. Pays-Bas—15, 280 (1896). Centralblatt, 1897—I, 257.

192. Compt. Rendus, 1902, 135, 1335-1337. Jour. of Chem. Soc. A, II, 209, 1902.

193. Compt. Rendus, 1902, 135, 1278-1283. Jour. of Chem. Soc., 1902, A, II, 222.

194. Gazz. Chim. ital. 28—1, 81-153.

TABLE No. 35.

GASES IN MINERAL SPRINGS.

	78	26	38	47	18	19	16*a*	16*b*
	Borden Spring, Luchon	Herculesbade, Peterstdorf, Austria	Norton Spring, Delft, Holland	Maizieris, Cote-d'or, France	Bagnoles, de l'Orne	Enkhuizen, North Holland	Monte Irone, Abano, Italy	Poretta Baths, Italy
Oxygen		3.00		2.0				
Carbon dioxid		1.70	8.2		5.0	10.8	15.0	
Methane	1.22	1.50	91.8			82.9	12.0	90.0
Nitrogen	96.22	93.80		N_2	90.5	6.3	72.0	
Argon	2.56			*Ar 98.0	4.5		present	2.0
Helium				He			trace	0.0
Hydrogen sulfid							trace	

GASES FROM SALT-MINES AND WELLS.

27*i* 1851 — *R. Bunsen.* Gas from the Knistersalze of Wieliczka, Austria.[195]

27*h* 1851 — *R. Bunsen.* Gas from a salt-well yielding petroleum, near Hanover, Germany.[195]

22 a+b 1860 — *Reichardt.* Analyses of gases from salt in the salt-mines at Stassfurt, Germany.[196]

11 a+b 1861 — *Pebal, L.* Analysis of a combustible gas from salt-mines at Wieliczka, Austria. Gas from a cleft in the rock salt.[197]

50 1879 — *H. Precht.* Composition of a combustible gas from Stassfurt, Germany, salt-mines.[198]

51 1879 — *F. Bischof.* Gas obtained by dissolving carnellite.[199]

21 1885 — *T. Hugh Bell.* Gas issuing from bore-hole in salt-beds at Middleborough, England.[200]

2 1885 1888 **a+b** — *P. Phillips Bedson.*[201] Gas obtained from deep salt borings at Middleborough, England.[202]

(*a*) at 1082 feet. 82 feet in salt.

(*b*) at 1106 feet.

78 1906 — *N. Costachescu.* Gases present in the rock salt and in the mud-volcanoes of Roumania. Two classes of gases.[203]

* Ar. is 2 per cent. of the unabsorbed residue.

195. Pogg. Ann. 83, 197. Jahresbericht (1851), 849.

196. Arch. Pharm. (2) 103, 347; Jahresbericht (1860), 830.

197. Ann. 118, 31—(1861).

198. Berichte 12, 557 (1879).

199. Ber. 12, 557 (1879).

200. Jour. Iron and Steel Inst. I, 1885, 180-182.

201. Jour. Soc. Chem. Ind. 7, 662 (1888).

202. Jour. Soc. Chem. Ind. 4, 650 (1885).

203. Ann. Sci. Univ. Jassy, 1906, 4, 3-50. Jour. Chem. Soc., abstracts II, 618, 1906.

TABLE No. 36.

GASES FROM SALT-MINES AND WELLS.

	27*i*	27*h*	22*a*	22*b*	11*a*	11*b*	50	51
	Kistersalz, Wieliczka, Austria	Hanover salt-well	Gas from Stassfurt salt	Gas from Stassfurt salt	Wieliczka, Austria, salt-mine gas mixed with air	Wieliczka, Austria, air-free gas	Stassfurt salt-mine gas.	Gas from Carnellite
Nitrogen	10.35	25.12	68.33	70.77	65.47	43.76	5.804	*9.55
Carbon dioxid	2.00	14.41	.....	.....	1.18	3.06	0.180	*3.00
Oxygen	2.58	.....	20.93	17.70	12.90	.....	0.185	*2.45
Methane	84.00	56.61	8.26	8.46	20.45	53.18	0.778	85 00
Hydrogen sulfid	.....	3.18	.....	.....	0.00	.....	.....	.....
Hydrogen	.....	.....	2.48	3.07	0.00	.....	93.053	.....
Carbon monoxid	.....	.....	.....	.....	0.00	.....	trace	.....
Totals	98.93	†99.92	100.00	100.00	100.00	100.00	100.00	100.00

* Air. † Some oil-vapors.

TABLE No. 36—CONCLUDED.

	21	2*a*	2*b*	2*c*	2*d*	78*a*	78*b*
	Middleborough, England, salt well	Middleborough, England, salt borings	Middleborough, England, salt borings	Middleborough, England, salt borings	Middleborough, England, salt borings	Rock salt, Roumania	Rock salt, Roumania
	Bell.	Gas and air, 1082 ft.	Gas free from air.	Gas and air, 1106 ft.	Gas free from air.	.....	.....
Nitrogen	16.8	96.57	97.95	96.8	99.6	trace	90.00
Carbon dioxid	.....	.....	.....	0.3	0.4	0.00	0.00
Oxygen	.....	1.53	.....	2.9	.....	trace	7.50
Methane	76.9	1.90	2.05	.....	.....	82.00	0.80
Hydrogen sulfid	.....	.....	.....	.....	.....	.....	.....
Hydrogen	.....	.....	.....	.....	.....	.....	.....
Carbon monoxid	.....	.....	.....	.....	.....	.....	.....
Ethylene	6.3	.....	.....	.....	.....	1.26	.....
Ethane	.....	.....	.....	.....	.....	9.80	1.55
Argon	.....	.....	.....	.....	.....	0.00	0.00
Totals	100.0	100.00	100.00	100.0	100.0	93.06	99.85

REGULAR NATURAL GASES.

25 1849 — *S. S. Howard.* **Gas from earth at Charlemont, Staffordshire.**[204]

9 1855 a+b — *C. Schmidt.* **Gases from peninsula of Apcheron, Northern Persia (now Southern Russia—Baku.)**[205]

9 1855 d, e, f, g. — *R. Bunsen.* **Gases from peninsulas of Kertsch and Tamen. (Southern Russia between Black Sea and Sea of Azov.)**[205] **Quoted by Abich.**[206]

204. Jahresbericht 1849—789.

205. Jahresbericht 1855, 1003.

206. Petersburg Acad. Bull. 14, 49.

9 1855 h. l. *Engler.* Gases from Pechelbronn *

1 1894 *Phillips, F. C.* Gases from Caspian region. Communicated to Mr. Phillips by M. Beliamin, of Nobel Bros., St. Petersburg.[207] Seem to be Bunsen's and Schmidt's old analysis, incorrectly copied.

7 1898 *Dawson, C.* Gas from 400-foot boring at Heathfield, Sussex, England. Two hundred pounds pressure. Odor of petroleum. Fifteen million cubic feet capacity. Anal. by S. A. Woodhead.[208]

8 1898 *Hewitt, J. T.* Gas from Heathfield, Sussex, England.[209]

8a 1908 *Dixon, H. B.*, and *Bone, W. A.* Analysis of natural gas at Heathfield, Sussex, England.[210] Analysis made in 1903 for Royal Commission on Coal Supplies.

52 1904 *Charitschkoff, K. V.* Composition of gas at Barekei, Daghestan, Russia.[211]

TABLE No. 37.

REGULAR NATURAL GASES.

				Gases from Peninsulas of Kertsch and Tamen.				
	25	9a	9b	9c	9d	9e	9f	9g
	Charlemont, Staffordshire, England	Peninsula of Apscheron (Baku)	Peninsula of Apscheron (Baku)	Titarovka Erdolberg	Jenikale Gas Springs	Boulganak Mud Volcano	Selennaiagora Central Crater	Jenikale Gas Springs
		C. Schmidt.		R. Bunsen.				
Methane	99.6	92.49	93.09	92.24	96.39	97.51	96.56	97.09
Carbon dioxid	0.3	0.93	2.18	3.50	4.61	2.49	4.44	2.11
Nitrogen	0.1	2.13	0.49	.....	.....	.....	.....	.....
Olefins	.....	4.11	3.26	4.26	.....	.....	.....	.....
Carbon monoxid	.....	.....	.....	.....	.....	.....	.....	.....
Hydrogen	.....	0.34	0.98	.....	.....	.....	.....	.....
Oxygen	.....	.....	.....	.....	.....	.....	.....	.....
Hydrogen sulfid	.....	.....	.....	.....	.....	.....	.....	.....
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Daunner Chem. Technology, vol. IV, p. 228.

207. Am. Chem. Jour. 16, 422—1894.

208. Quart. Jour. Roy. Geol. Soc., Aug. 5, 1898, 54, 564-571.

209. Quart. Jour. Geol. Soc. 1898, 54, 572-573.

210. Proc. Chem. Soc. 19, 63; Jour. Soc. Chem. Ind. 1902, 1225 and 1903, 410.

211. Russk. Phiz. Khim. Obsch. 36, 321-326, 1904, J. Soc. Chem. Ind. 1903, 1190.

TABLE No. 37—CONTINUED.

	9h	9i	1a	1b	1c	1d	1e	1f	52
	Gas from Pechelbronn.		Gases from Caspian region same as 9a–9f, but contain errors due to copying.						Barekei, Daghestan, South Russia.
	Engler.								
Methane	77.3	77.3	92.49	93.07	92.24	95.39	97.57	95.56	65.84
Carbon dioxid	3.6	3.6	0.95	2.18	3.50	0.00	2.47	4.44	12.82
Nitrogen	8.9	9.0	2.13	0.49	.....	.....	.....	.....	.....
Olefins	4.8	4.8	4.11	3.26	4.26	0.00	0.00	0.00	.....
Carbon monoxid	3.5	3.4	0.00	0.00	0.00	0.00	0.00	0.00	.....
Hydrogen	.....	.....	0.94	0.98	0.00	0.00	0.00	0.00	.....
Oxygen	1.8	2.0	.....	.....	.....	.....	.....	.....	.....
Hydrogen sulfid	.....	.....	.....	.....	.....	.....	.....	.....	.....
Ethane	.....	.....	.....	.....	.....	.....	.....	.....	19.92
	99.9	100.1	100.62	99.98	100.00	*95.39	100.04	100.00	98.58

* Partial analysis.

TABLE No. 37.—CONCLUDED.

	7	8	8a
	Heathfield gas, Sussex, England.		
	Dawson.	Hewitt.	Dixon, Bone.
Methane	72.5	91.9	93.16
Higher hydrocarbons	5.5	0.0	.....
Carbon dioxid	4.0	0.0	.....
Oxygen	18.0	0.0	.....
Carbon monoxid	0.0	0.0	1.00
Olefins	.....	0.0	.....
Nitrogen	.....	0.9	2.90
Hydrogen	.....	7.2	.....
Ethane	.....	.....	2.94
Ammonia	0.0	.....	.....
Hydrogen sulfid	0.0	.....	.....
	100.0	100.0	100.00

GASES FROM BORINGS.

13 1832 **Hydrocarbon gas from boring of artesian well at Johnstone, England.**[212] **"Gas burned with a non-luminous blue flame and seemed to be pure hydrocarbon gas."**

23 1861 ***Kauer, A.,* and *G. Bizio.* Analysis of a gas mixture from the spring in Campo St. Paolo at Venice.**[213]

41 1881 ***M. Scholz.* Gas from a bore-hole near Griefswald.**[214]

42 1885 ***R. Emerling.* Gas from a bore-hole near Apenrade, North Germany (Schlesweg).**[215]

215. Jahresbericht 1885, 2311.

212. Dingler's Polytechnic Jour. 44, 398 (1832). Ann. 7, 345 (1833).

213. Sitz K. ak. Wiss. Wien 44, pt. 2, 69-70 (1861). Jahresbericht 1861, 1116.

214. Jahresbericht 1884, 2030.

55 No date. *Bischof.* Gas from bore-hole for artesian well in Schaumburg, Germany (after removal of carbon dioxid).[216]

54 a+b 1899 *J. Lorie.* Inflammable gas from the Netherlands. Locality not given. Gases from bore-holes.[217]

TABLE No. 38.

	23	41	42	55	54*a*	54*b*
	Campo St. Paolo, Venice.	Griefswald.	Apenrade, N. Germany.	Schaumburg.	Boreholes, Holland.	Boreholes, Holland.
Methane	79.45	35.90	92.38	79.10	*97.7	*74.8
Carbon dioxid	4.05	.....	3.00	.....	10.4	8.4
Nitrogen	16.50	34.43	4.62	4.79	9.0	16.2
Carbon monoxid	.....	27.53	.....	.....	.....	0.6
Hydrogen	.....	2.12	.....	.....	0.4	4.6
Oxygen	.....	.....	traces	.....	0.5	0.4
Olefins	.....	.....	.....	16.11	.....	.....
	100.00	99.98	100.00	100.00	118.0	100.0

* Should be 79.7, probably.

GASES FROM RIVERS, LAKES, MARSHES, ETC.

24 1850 *Maumeme.* Gas given off by water in an arm of the river Vesle, near Rheims, France, which is strongly charged with refuse from tributary sewers.[218]

(*a*) Collected June 18, 1849.

(*b*) Collected January 26, 1850.

27 g_1 and g_2 *R. Bunsen.* Marsh-gas from a pond in the Marburg Botanical Gardens, Germany.[219]

(g_1) In summer.

(g_2) In winter.

29 1857 *Deville* and *Le Blanc.* Gases from various places in Sicily.[220]

(*a*) Gas from sulfur water of Santa-Venerina near Aci-Reale (after long keeping.)

(*b*) Fresh gas from above source.

(*c*) Gas from Maculuba, at Girgenti.

(*d*) Gas from muddy, strongly salt water in Val Corrente of valley of San Biaggio, near Paterno.

(*e*) Gas from opening filled with salty water at Paterno.

(*f*) From the acqua rossa near Paterno.

(*g*) From the lake of Palici or Lago di Naftia.

(*h*) From the Maculuba of Xirbi.

(*i*) From the Maculuba de Terrepilata at Caltanisetta.

216. Groves and Thorpe's Chemical Technology, vol. I, pp. 60.

217. Jour. Chem. Soc. London Abstracts, 1900. Tijdsehr K. Nederl. Ard Genootsch rks. 2 dl. XVI, pp. 143-177.

218. Compt. Rendus 31, 270. Jahresbericht 1850, 626.

219. Pogg. Ann. 83, 197. Jahresbericht 1851, 849.

220. Jahresbericht 1857, 716.

39 1874 *Andrews.* Composition of an inflammable gas issuing from a silt bed in Belfast, Ireland.[221]

4 1885 *Bishop's Chem. Geol.* Composition of gas issuing from marsh ground.[222]

56 1902 *Charitschkoff.* Analysis of combustible gas evolved in the Caspian Sea, near the Gulf of Baku.[224] Two samples.

TABLE No. 39.

GASES FROM RIVERS, LAKES, MARSHES, ETC.

	24*a*	24*b*	27g_1	27g_2	29*a*	29*b*	29*c*	29*d*	29*e*
	River Visle, Rhelms, France.	River Visle, Rhelms, France, Jan. 26, 1850.	Marsh-gas at Marburg Botanical Gardens.		Santa Venerina, old, Sicily.	Santa Venerina, fresh, Sicily.	Girgente, Sicily.	Val-Corrente, Sicily.	Paterno, Sicily.
Methane	48.4	42.5	47.37	76.61	83.6	95.5	90.4	*32.5	5.0
Ethane									
Ethylene	6.3	6.6							
Carbon dioxid	18.0	8.5	3.10	5.36	4.2	3.1	1.2	67.0	90.7
Carbon monoxid	14.2	21.8							
Oxygen	0.3	0.4	0.17			1.2	1.7	0.5	1.0
Hydrogen	10 0	18.3							
Nitrogen	2.8	1.9	49.39	18.03	12.2		6.7		3.3
Hydrogen sulfid						0.2			
Totals	100.0	100.0	100.03	100.00	100.0	100.0	100.0	100.0	100.0

* With nitrogen.

TABLE No. 39—CONCLUDED.

	29*f*	29*g*	29*h*	29*i*	4	39	56*a*	56*b*
	Acqua Rossa, Paterno, Sicily.	Lake of Palici, Sicily.	Maculuba of Xirbi, Sicily.	Maculuba de Terrepilata, Sicily.	Gas from marsh ground.	Silt-bed, Belfast, Ireland.	Caspian Sea, Gulf of Baku.	Caspian Sea, Gulf of Baku.
Methane		0.7	73.7	41.0	47.37	83.75	96.28	95.17
Ethane						0.00		
Ethylene						0.00		
Carbon dioxid	93.2	94.7	0.7	0.3	3.10	2.44		
Carbon monoxid								
Oxygen	1.0	1.1	5.2	12.3	0.17	1.06		
Hydrogen								
Nitrogen	5.8	3.5	20.4	46.4	49.39	12.75	3.72	4.83
Hydrogen sulfid								
Totals	100.0	100.0	100.0	100.0	100.03	100.00	100.00	100.00

46 1869 *Fouqué* and *Gorceix.* Analyses of a series of gases partly from the Tuscan Lagoons (Lagonian Toscanio), partly from the Apennines.[223] Many of the gases also contain traces of higher hydrocarbons, as is shown by the odor.

221. Chem. News 30, 138, 1874.

222. Bishop's Chem. Geol. I, 730.

223. Compt. Rendus 69, 946; Jahresbericht 1869, p. 1276.

224. J. Russ. Phys. Chem. Soc. 1902, 34, 712-713.

46
1869

TABLE No. 40.

GASES FROM TUSCAN LAGOONS AND THE APENNINES.

		Carbon dioxid.	Nitrogen.	Hydrogen.	Methane.	Hydrogen sulfid.	
1	Larderello	90.47	1.90	1.43	2.00	4.20	Temperature about 100° C.
2	Castell Nuovo	92.63	1.08	0.90	1.63	3.76	
3	Sasso	88.33	1.55	2.01	2.55	5.43	
4	Serrazzano	87.90	2.93	2.10	0.97	6.10	
5	Barigazzo	1.58	1.81	.....	96 61	.....	
6	Monte Creto	0.53	1.22	.....	98.25	.....	
7	Bocca Suolo (*a*)	2.32	1.52	.....	96.16	.....	
8	Bocca Suolo (*b*)	2.38	0.30	.....	97.32	.....	
9	Veta	1.51	2.14	.....	96.35	.....	
10	San Venanzio	0.52	10.16	.....	89.32	.....	
11	Sassuolo	0.56	1.38	.....	98.06	.....	
12	Salvarola	0.79	3.63	.....	95.58	.....	
13	Pietra Mala Vulcano	1 54	2.27	.....	96.19	.....	
14	Pietra Mala Vulcanello	1.75	0.77	.....	97.48	.....	
15	Pietra Mala Acqua Buja	0.74	0.41	.....	98.85	.....	
16	Berguleo	0.48	0.59	.....	98.93	.....	
17	Riolo	1.01	1.64	.....	97.35	.....	
18	Sassuno	1.14	0.39	.....	80.60	.....	C_2H_6 17.87
19	San Martino del Pedriolo	1.12	6.20	.....	92.68	.....	
20	Poretta, Leone	5.97	4.61	.....	89.42	.....	
21	Poretta, Gasometer	2.12	1.57	.....	95.91	.....	
22	Poretta, Bovi	5.72	2.06	.....	92.22	.....	
23	Poretta, Marte	5.06	2.78	.....	92.16	.....	
24	Poretta, Puzzola	1.84	6.68	.....	91.48	.....	
25	Poretta, Vechhia	2.02	7.23	.....	90.75	.....	
26	Poretta, Sasso Cardo	2.05	3.13	.....	94.82	.....	
27	Fosso di Bagni	0.61	8.04	.....	91.35	.....	
28	Gaggio Montano	1.23	2.01	.....	96.76	.....	

MINE GASES.

1846
England
14 *Graham.* Composition of mine gas in coal-mines at Newcastle, England.[225]

1851
Germany
27*k* *Bunsen.* Mine gas from coal strata (Stein Kohlen flötzen) (Coal Measures [?]) at Oberkirschen.[226]

1879
England
44 *J. W. Thomas.* Gas from shaft of Abercarn colliery.[227]

1881
Silesia
40 *Th. Poleck.* Mine gases from Vereinigten Glück hilf grube' Silesia.[228]

1873
Wales
6 *J. W. Thomas.* Blower in coal-pit, South Wales.[229]

12
1896
Sweden *Gustaf Nordenström.* Inflammable gases in metalliferous mines of Sweden.[230] Source of gas unknown. Not decaying woodwork.

1902
76 *N. S. Kurnakoff.* Composition of fire-damps, from the coal-mine of the Donetz.[231]

79 Miscellaneous analyses of fire damp from English mines.[232] Analyses by various analysts from various sources. Credit is given in the table.

225. Phil. Mag. 28, 437. Review in Ann. 60, 218 (1846).

226. Pogg. Ann. 83, 197. Jahresbericht 4 (1851), 849.

227. Chem. News, 1879—39, 27.

228. Jahresbericht, 1884, 2030.

229. J. Chem. Soc. 1876, 793.

230. Jahrbuch f. Min., 1899, Ref. 262.

231. J. Russ. Phys. Chem. Soc., 1902—34, 654-659. Jour. of Chem. Soc. Abstracts, 1903, II, 156.

232. Groves & Trorpe's Chemical Technology, vol. I, p. 61.

TABLE No. 41.

GASES FROM MINES.

Miscellaneous Analyses.

CONSTITUENTS.	14*a*	14*b*	27*k*	44*a*	44*b*	40*a*	40*b*
	Mine Gas at Newcastle, England.		Coal Measures, Oberkirschen.	Abercorn colliery.	Abercorn colliery.	Vereinigten Gluckhilf grube, Silesia.	
Methane	94.2	82.5	97.53	49.11	74.63	34.93	32.65
Ethane	.....	.....	.....	0.95	0.81	2.89	3.99
Propane	.....	.....	.....	.....	.....	.....	.....
Carbon dioxid	.....	.....	.....	2.54	2.43	41.49	41.49
Carbon monoxid	0.0	0.0	2.61	.....	.....	.....	1.87
Olefins (ethylene)	0.0	0.0	.....	.....	.....	.....	.....
Hydrogen	0.0	0.0	.....	.....	.....	.....	.....
Oxygen	1.3	1.0	0.45	.....	0.00	.....	.....
Nitrogen	4.5	16.5	7.16	34.35	22.13	20.69	20.00
Air	.....	.....	.....	13.05	0.00	.....	.....
	100.0	100.0	107.75	100.00	100.00	100.00	100.00

TABLE No. 41—CONCLUDED.

CONSTITUENTS.	6	12*a*	12*b*	76*a*	76*b*	76*c*
	Blower Coal-pit, S. Wales.	Anneberg, Sweden.	Dannemora, Sweden.	Fire-damps, Donetz, Russia.		
Methane	94.42	51.0	33.6	64.91	51.96	61.08
Ethane	.....	.....	.....	.....	.....	.....
Propane	.....	.....	.....	.....	.....	.....
Carbon dioxid	0.60	1.5	.....	1.04	0.29	0.57
Carbon monoxid	.....	1.2	.....	.....	.....	.....
Olefins (ethylene)	.....	0.5	.....	.....	.....	.....
Hydrogen	.....	1.0	.....	.....	.....	.....
Oxygen	.....	.....	.....	3.60	8.09	3.81
Nitrogen	3.98	44.8	66.4	30.45	39.66	34.50
	98.00	100.0	100.0	100.00 *	99.95	99.96

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TABLE No. 42.

ANALYSES OF FIRE-DAMP FROM ENGLISH MINES.

Groves and Thorpe's Chemical Technology, vol. I, p. 61.

	Colliery or Pit.	Seam or Source of Coal.	Methane.	Air.	Nitrogen.	Oxygen.	Carbon dioxid.	Hydrogen.	Ethylene or Olefins.	Authority or analyst.
1	Wallsend	Bensham	91.00	9.00						Turner.
2	Wallsend	Bensham	77.50		21.10		1.30			Playfair.
3	Wallsend	Pipe above ground	92.80		6.90	0.60	0.30			Playfair.
4	Hepburn	Twenty-four feet below Bensham	91.80		6.70	0.90	0.70			Playfair.
5	Hepburn	Ditto, a month after	92.70		6.40		0.90			Playfair.
6	Hepburn	Bensham	86.50		11 90		1.60			Playfair.
7	Hepburn	Bensham				0.60				Graham.
8	Jarrow	Bensham	81.50	18.50						Turner.
9	Jarrow	Bensham	83.10		14.20	0.40	2.10			Playfair.
10	Jarrow	Five-quarter	93.40		4.90		1.70			Playfair.
11	Jarrow	Low main	79.70		12.30	3.00		3.00		Playfair.
12	Jarrow	Ditto, 11 fathoms lower	89.00	11.00						Turner.
13	Burraton	Yard coal	91.00	9.00						Turner.
14	Killingworth	High main	85.00	8.00	7.00					Turner.
15	Killingworth	Low main	37.00	46.50	16.50					Turner.
16	Killingworth		82.50		16.50	1.00				Graham.
17	Killingworth		66.30	23.35	6.32		4.03			Richardson.
18	Hetton	Main, 100 fathoms	50.00	23.00	27.00					Turner.
19	Hetton	Hutton, 175 fathoms	50.00	6.00	44.00					Turner.
20	Pensher	Hutton, waste 125 fathoms	7.00	82.00	11.00					Turner.
21	Townley	Three-quarter seam	56.17	33.15	4.68		6.00			Richardson.
22	Well-gate	Five-quarter	98.20		1.30		0.50			Playfair.
23	Gateshead	Five-quarter	94.20		4.50	1.30				Graham.
24	Cym-Twrch		19.30		63.80	15.50	0.90			Playfair.
25	Wellsweiler		87.43		2.22		4.30		6.05	Bischof.
26	Gerhardt		79.84		14.36		3.90		1.90	Bischof.

TABLE No. 43.

GASES OCCLUDED IN COAL.

45 *Analyses by Ernst von Meyer.*

LOCALITY.	Cubic cm. of gas yielded by 100 gms. coal at 20° C.	Carbonic acid.	Oxygen.	Nitrogen.	Marsh-gas.	Ethane.
ZWICKAU.						
I. "Schichtenkohle:" 700 meters deep; fresh winning	38.0	2.42	2.51	23.17	71.90	
II. (*a*) Do.; 690 meters deep; had been exposed during 5 years to the ventilation air-current of the pit	18.2	16.70	4.90	55.15	3.17	18.61
(*b*) Do.; gas collected a week after (*a*) had been collected	.....	11.40	3.80	60.98	3.44	18.88
(*c*) Do.; gas collected a fortnight after (*b*) had been collected	.....	12.10	1.10	65.16	3.19	16.85
(*d*) Do.; gas collected 3 or 4 months after (*c*) had been collected, during which time the coal was left in a cool, dry place	.....	12.91	2.57	57.84	4.06	22.68
(*e*) A portion of the same coal as (*d*) in nuts was kept heated to 45° C., with free access of air, and then treated as the others to expel the gas, which escaped not more slowly than from the coal not heated	.....	10.65	3.20	74.72	.....	9.80
(*f*) Used for gas-making at Leipzig. [At 15° C.]	34.7	2.71	0.16	29.39	59.61	7.68
(*g*) Gas evolved by the usual treatment after the coal had been previously heated during 25 hours at a constant temperature of 50° C.	.....	15.60	3.10	73.12	.....	2.04
III. "Zachkohle": 680 meters deep; fresh winning	25.5	4.02	0.62	50.36	45.00	
IV. Do.; 656 meters deep; exposed during 1½ years to the ventilation air-current; showed traces of weathering externally	18.6	2.25	0.70	23.89	73.16	
V. "Lehekohle": 560 meters deep; fresh winning	52.8	0.60	trace.	48.00	51.40	
VI. (*a*) Do.; 690 meters deep; had been exposed during 5 years to the ventilation air-current; appeared outwardly weathered	13.6	7.62	2.44	50.75	15.88	22.35
(*b*) Do.; gas collected a week after (*a*) had been collected	.....	10.10	2.60	50.53	10.18	23.32
(*c*) Do.; gas collected two months after (*b*) had been collected	.....	11.18	2.82	67.99	.....	16.36
FROM THE "PLANEN'SCHE FORMATION."						
(These coals were rich in disseminated iron pyrites; they were grayish black without the luster of true carboniferous coals.)						
VII. "Harter Schiefer": evolved gas copiously; freshly gotten	not det.	48.7	1.8	4.95		
VIII. "Weicher Schiefer": evolved gas copiously; freshly gotten	not det.	38.2	1.2	60.6		
IX. "Maschinenschiefer": evolved gas most copiously; freshly gotten	not det.	54.9	1.2	43.9		

TABLE No. 43—CONCLUDED.

LOCALITY.	Cubic cm. of gas yielded by 100 gms. coal at 20° C.	Carbonic acid.	Oxygen.	Nitrogen.	Marsh-gas.	Hydrid of ethyl.
WESTPHALIA.						
X. "Zollverein" pit, near Essen, gas coal,	22.5	7.50	2.59	89.91		
XI. "Consolidation" pit, near Essen; gas coal	17.4	2.56	4.11	58.48	24.85	
XII. (*a*) "Sonnenschein" seam, near Bochum; laminated with occasional iron pyrites; freshly gotten	50.6	4.87	2.66	75.82	16.65	
(*b*) Do.; had been exposed during a year to the ventilation air-current of the pit	43.2	11.12	2.88	78.60	7.40	
XIII. (*a*) "Dickebank" seam; very like XII (*a*); freshly gotten	43.3	2.18	2.12	70.51	25.19	
(*b*) Do.; had been exposed for a year to ventilation current	41.2	15.84	3.06	74.53	6.57	
XIV. (*a*) "President" seam; not distinctly schistose; freshly gotten	59.2	5.82	1.99	60.62	31.57	
(*b*) Do.; exposed during a year to ventilation air-current	43.6	7.68	2.24	86.77	3.31	
XV. (*a*) "Wilhelm" seam; not distinctly schistose; freshly gotten	54.4	1.30	1.60	66.85	30.25	
(*b*) Do.; exposed for a year to ventilation current	39.2	4.35	3.35	81.18	11.12	
XVI. (*a*) "Franziska" seam; distinctly schistose; rich in iron pyrites; freshly gotten,	54.5	2.02	0.90	86.43	10.65	
(*b*) Do.; exposed during a year to ventilation current	39.6	2.15	3.14	91.28	3.43	
XVII. (*a*) "Leonhard" seam; distinctly schistose and contains iron pyrites; freshly gotten	42.0	3.72	0.39	90.19	5.70	
(*b*) Do.; exposed during a year to ventilation current	3.64	8.49	3.57	87.94	trace	

All the specimens from XII to XVII, inclusive, were from "Constantine the Great" colliery, near Bochum, and are arranged in the order of their geological age, beginning with the oldest, No. XII.

TABLE No. 43—CONCLUDED.

LOCALITY.	Cubic cm. of gas yielded by 100 gms. coal(?) at 20° C.	Carbonic acid.	Oxygen.	Nitrogen.	Marsh-gas.	
NORTHUMBERLAND AND DURHAM.						
I. From the low main seam, Bewicke Main Colliery.....	25.2	5.55	2.28	85.65	6.52	Weathered externally.
II. From the Maudlin seam, Bewicke Main Colliery.....	30.7	8.54	2.95	61.97	26.54	Very hard, bright, with conchoidal fracture.
III. From the main coal seam, Urpeth Colliery.....	27.0	20.86	4.83	74.31	.....	Bright fracture.
IV. From the five-quarters seam, Urpeth Colliery, about 30 fathoms from surface.....	24.4	16.51	5.65	77.84	trace	Bright fracture.
V. From the five-quarters seam, Wingate Grange Colliery, 74 fathoms from surface.....	91.2	0.34	trace	13.86	85.80	Here and there fibrous in structure.
VI. From the low main seam, Wingate Grange Colliery, 108 fathoms from surface.....	238.0	1.15	0.19	14.62	84.04	
VII. From the Harvey seam, Wingate Grange Colliery, 148 fathoms from surface.....	211.2	0.23	0.55	9.61	89.61	Very hard, containing iron pyrites, with bright conchoidal fracture.
VIII. From the upper or Harvey seam, Woodhouse Close Colliery, 25 fathoms from surface.	84.0	5.31	0.63	44.05	50.01	

TABLE No. 44.

GASES GIVEN OFF ON HEATING COAL IN A VACUUM TO 100° C.

45*a* *J. W. Thomas* (Groves and Thorpe's Chemical Technology, vol. I, p. 86.)

SAMPLE OF COAL.	Gas evolved by 100 grms. at 100° C. in a vacuum.....	Carbonic anhydrid CO_2.....	Marsh-gas, CH_4.....	Hydrid of ethyl, C_2H_6.....	Ethyl $(C_2H_5)_2$.....	Nitrogen.....
Wigan cannel 5-3 seam 350 yards deep.....	421.3 cc.	6.44	80.69	4.75	.....	8.12
Wigan cannel 3-2 seam 600 yards deep.....	350.6 cc.	9.05	77.19	7.80	.....	5.96
Scotch (Heywood) cannel, Wilsontown...	16.8 cc.	53.94	.....	.....	.....	46.06
Scotch (Lesmahagow) cannel.....	55.7 cc.	84.55	.....	.....	C_2H_6 0.91	14.54
Whitehill cannel shale, Lasswade.....	55.7 cc.	68.75	.....	2.67	.....	28.58
Whitby jet (finest quality).....	30.2 cc.	10.93	.....	.....	86.90	2.17

GASES ENCLOSED IN COAL, ETC.

45 1872 *E. von Meyer.* Composition of gases enclosed in coal.[233] Gases driven off on heating the coal sample in water, without allowing it to boil.

45*a* *J. W. Thomas.* Gases given off on heating coal in a vacuum to 100° C.[234]

233. Jour. prak. Chem., (2) 5, 144. Jahresbericht, 1872, 1045-1050. Groves & Thorpe's Chemical Technology, vol. I., pp. 84, 85.

234. Groves & Thorpe's Chemical Technology, vol. I, p. 86.

CHAPTER VIII.

THE CHEMICAL COMPOSITION OF PETROLEUM.

By F. W. Bushong.

PETROLEUM consists of an extremely complex mixture of very closely related substances, chiefly compounds of carbon and hydrogen. In addition to these essential constituents, crude oils generally contain also widely varying quantities of compounds of sulfur, nitrogen, oxygen and minute quantities of other elements.

The following table shows ultimate chemical analyses of a number of crude oils that differ much in their physical properties, and, for comparison, an analysis of gilsonite, a variety of asphalt:

Sp. gr.	Field.	Carbon.	Hydrogen.	Sulfur.	Nitrogen.
.....	Pennsylvania[235]	86.06	13.89	0.06	.....
0 8095	Oil City, Pa.[236]	85.80	14 04	.....	.....
0.8367	Welker, Ohio[236]	85 46	13 91	0 48	.....
0.836	Findlay, Ohio[236]	84 57	13 62	0 72	0.11
0.862	Petrolia, Canada[236]	83 94	13.37	0 99	.....
0.865	Cherryvale, Kan.[237]	85 43	13.07	0.37	.....
.....	Baku, Russia[235]	86 25	13.48	.....	.....
0.912	Humboldt, Kan.[237]	85.63	12.44	0.37	.....
0.912	Beaumont, Tex.[238]	85.05	12 30	1.75	.....
0.912	Ventura, Cal.[239]	84.00	12.70	0.40	1.70
0.940	Humboldt, Kan.[237]	85.33	11.80	0 15	.....
0.9458	McKittrick, Cal.[240]	86 06	11.45	0 87	.....
0.9845	Santa Barbara, Cal.[236]	86 32	11.70	0.84	.....
Gilsonite	Wasatch Range, Utah[241]	86 86	11.89	0 64	0.02

235. Engler: Ber. d. deutsch. Chem. Ges., 28, 2501, 1895.

236. Mabery: Amer. Chem. Jr.. *17*, 713, 1895; *18*, 55, 149, 165, 1896; Proc. Amer. Acad. A. and S., *40*, 323, 1904.

237. Bartow and McCollum: Trans. Kan. Acad. Sci., *19*, 58, 1903.

238. Richardson: Jr. Franklin Inst., *162*, 113, 1900.

239. 18th Ann. Rep. U. S. G. S., 842, 1896-'97.

240. O'Neill: Jr. Amer. Chem. Soc., *25*, 699, 1903.

241. Mabery and Byerly: Amer. Chem. Jr., *18*, 149, 1896.

HYDROCARBONS OF THE SERIES C_nH_{2n+2}. PARAFFINS AND ISOPARAFFINS.

All hydrocarbons of this series are saturated.[242]

1. *Gases.*[243]

Five gaseous saturated hydrocarbons are found dissolved in petroleum whose molar weights are 16, 30, 44, 58 and 58, corresponding to the formulæ CH_4, C_2H_6, C_3H_8, C_4H_{10} and C_4H_{10}, respectively. In percentage composition also they agree theoretically with these formulæ. According to our modern theories of structural chemistry there should be two isomers of the formula C_4H_{10}, but no isomers of lower molar weight. All the gaseous hydrocarbons, therefore, that are theoretically possible in this series, occur in petroleum. The first of these is methane, or marsh-gas, the principal constituent of natural gas. The others, ethane, propane, butane and isobutane, occur in relatively small quantities.

2. *Liquids.*

Liquid saturated hydrocarbons corresponding in percentage composition and in molar weight to all possible empirical formulæ from C_5H_{12}, pentane, to $C_{16}H_{34}$, hexadecane, have been isolated from Pennsylvania petroleum. They range in density between 0.626 at 0° to 0.7925 at 20°, and in boiling-point between 37° and 275°. The number of isomers theoretically possible within these limits is very great; so great that in many cases the difference in boiling-point between the different chemical individuals may be only a fraction of a degree, so that their separation by means of fractional distillation is impossible.

3. *Solids.*

With only three exceptions, all the members of the paraffin series having molar weights corresponding to the empirical formulæ from $C_{16}H_{34}$ up to $C_{35}H_{72}$ have been found in petroleum. The three exceptions, heptacosane ($C_{27}H_{56}$), triacontane ($C_{30}H_{62}$) and tritriacontane ($C_{33}H_{68}$) have been found in paraffin obtained from German brown coal.[244] These hydrocarbons range in melting-point between 10° and 76°, and the specific gravity of the highest member reaches 0.805 at 80°. It is probable that further research will reveal the presence of still

242. A saturated hydrocarbon is one that is not capable of uniting with more hydrogen. An unsaturated hydrocarbon may unite with hydrogen to form a saturated hydrocarbon. Ex. $C_2H_4+H_2=C_2H_6$.

243. Ronalds, Jahresbericht der Chemie, *1865*, 507, c. f. Jour. Amer. Chem. Soc. *30*, 142; 1908.

244. Krafft. Berichte d. d. chem. Ges. *40*, 4779; 1907.

higher members of this series. Mabery has isolated solid paraffins from Pennsylvania petroleum that had not been subjected to distillation. It is, therefore, believed that the above-mentioned hydrocarbons exist naturally in the crude petroleum and are not products formed during the process of distillation.

HYDROCARBONS OF THE SERIES C_nH_{2n}.

1. *Naphthenes.*[245] Saturated Monocyclic Hydrocarbons.

Some Russian oils contain as much as 80 to 90 per cent. of naphthenes. Young,[246] in examining American petroleum, isolated a number of members of this series, but found them only in relatively small quantities. Mabery has found compounds of the formula C_nH_{2n} in petroleum from Ohio, Texas and California, and also from foreign fields, which are believed to be naphthenes.

The following are some of the naphthenes that have been found in American petroleum:

Name.	Formula.	Boiling-point.	Density.
Pentamethylene	C_5H_{10}	50°	0.700
Hexamethylene	C_6H_{12}	80.6°	0.7722
Methylpentamethylene	C_6H_{12}	72°	0.7660
Methylhexamethylene	C_7H_{14}	102°	0.7964

2. *Ethylenes.* Unsaturated Paraffin Derivatives of Formula C_nH_{2n}.

"In the earlier literature on petroleum it was generally assumed that the ethylene hydrocarbons, series C_nH_{2n}, formed a considerable proportion of the constituents, and even after the discovery of the cyclic series C_nH_{2n}—the naphthenes, according to the earlier nomenclature of Markownikow—many writers, with no foundation on facts, still insist on the presence of ethylene hydrocarbons. It is now safe to assert that these bodies are present in any petroleum at most in very small amounts."—*Mabery.*[247]

"According to Lachowicz, ethylenes are not present in Galician petroleum, and it is his opinion, shared also by Engler, that in those cases where they have been found they were products formed during distillation."—*Höfer.*[248]

HYDROCARBONS OF THE SERIES C_nH_{2n-2}, NAPHTHYLENES.

In Louisiana petroleum[249] a series of saturated hydrocar-

245. Die Naphthene, Cyclische Polymethylene des Erdöls, R. A. Wischin.

246. Jour. Chem. Soc. London, LXXIII, 905; 1898.

247. Jour. Amer. Chem. Soc., XXVIII, 415; 1906.

248. Das Erdol und seine Verwandten, 2te Aufl. Hans Höfer, p. 65.

249. Coates, Jour. Amer. Chem. Soc. 28, 384; 1906.

bons, probably bicyclic naphthenes, having an odor strongly resembling turpentine, has been isolated:

Formula.	Density.	Boiling-point.	Refractive index.
C_8H_{14}.....	0.7747 at 24°	120.5°	1.4260 N 25/D
C_9H_{16}.....	0.7992 at 24°	145.7°	1.4370 " "
$C_{10}H_{18}$.....	0.8146 at 22°	168°-170°	1.4460 " "
$C_{11}H_{20}$.....	0.8378 at 26°	198°-200°	1.4582 " "
$C_{12}H_{22}$.....	0.8511 at 28°	215°-217°	1.4640 " "
$C_{13}H_{24}$.....	0.8629 at 22°	235°-238°	1.4692 " "

Hydrocarbons of higher molar weights having the same general formula have been found by Mabery in petroleum from Ohio, California and other fields.

Hydrocarbons of the Series C_nH_{2n-4}, Terpenes.

Members of this series occur generally in small quantities in all the lighter petroleums, but they are more especially found in the heavier varieties, Louisiana, Texas and California. By their tendency to oxidize and to polymerize the terpenes are believed to contribute to the viscosity and resinification of the heavier oils. They may be originally present in the crude oils, but to a greater or less extent they are formed, or undergo chemical changes, during distillation at high temperatures.

Hydrocarbons of the Series C_nH_{2n-6}, Benzene Series.

The aromatic hydrocarbons benzene, toluene, xylenes, mesitylene, cymene, durene, isodurene and other homologues of benzene are very widely distributed constituents of petroleum. According to Mabery, California petroleum contains much larger proportions of the aromatic hydrocarbons, especially of the xylenes and others having higher boiling-points.

Hydrocarbons Containing Less Hydrogen than Those Above-Mentioned.

Mabery has identified two members of the series C_nH_{2n-6} in heavy California petroleum. Markownikow and Ogloblin[250] have found, in Russian petroleum, members of the series C_nH_{2n-8}, C_nH_{2n-10} and C_nH_{2n-12}. Naphthalene, $C_{10}H_8$, has been obtained in crystals from distillates of petroleum from California, Bavaria and Hanover.

Oxygen Compounds in Petroleum.

According to Markownikow and Ogloblin, substances having the properties of phenols are present in small amounts in all the distillates from the petroleum of Baku, but in the kerosene fraction 220°-230° the total oxygen content was found to be as

250. Berichte d. deutsch. chem. Ges., *16*, 1873; 1883.

much as 5.21 per cent. They found that the products containing oxygen were chiefly neutral, but partly of acid character. They isolated several acids, one of which proved to be identical with an acid found in Roumanian petroleum by Hell and Medinger.[251] Aschan[252] later proved these acids to belong to a class to which he gave the name naphthene carboxylic acids, which have the general formula $C_nH_{2n-2}O_2$.

These acids, which are formed in the crude oils as well as their products through contact with oxygen from the air, are capable of attacking metals, thereby dissolving them in appreciable amounts. They also dissolve sulfur readily.

Sulfur Compounds in Petroleum.

Richardson and Wallace[253] separated sulfur in the form of crystals from Beaumont oil. Thiele[254] found 63.63 per cent. amorphous sulfur and 6.81 per cent. crystalline sulfur in the sediment in a tank-car which had contained Beaumont oil.

Hydrogen sulfid is very generally emitted by oils that contain sulfur in considerable quantities; and its alkyl derivatives, methyl sulfid, ethyl sulfid and higher homologues of the series $(C_nH_{2n+1})_2S$ have been found in Lima oil, while compounds of a series $C_nH_{2n}S$, which appear to be cyclic in structure, have been found in Canadian petroleum.[255]

Nitrogen Compounds in Petroleum.

California petroleum is specially rich in nitrogen bases of the pyridin or hydropyridin and chinolin type. Peckham[256] found more than one per cent. of nitrogen in several samples which he examined. Mabery found as much as two per cent. of nitrogen in other samples, and estimates from this that the basic nitrogen compounds make up 20 to 25 per cent. of the crude oil. Pennsylvania oils contain only traces of nitrogen.

The Examination of Kansas Petroleum.

At the present time no uniform methods for the examination of petroleum have been generally adopted by chemists, but a committee for the unification of methods of testing petroleum

251. Berichte d. deutsch. chem. Ges. 7, 1216; 1874, *10*, 451; 1877.

252. Berichte d. deutsch. chem. Ges. *23*, 867; '93; *24*, 1864; '94,; *25*, 3661, '95.

253. Eng. Mining Jour. *73*, 352; 1902.

254. Chem. Zeit. *26*, (77) 896, J. Soc. Chem. Ind. 1902, 1271.

255. Proc. Amer. Acad. A. and S. *41*, 89; 1905.

256. Rept. Geol. Sur. Cal. *2*, 89. Amer. Jour. of Sci. (3) *48*, 250; 1894.

products, appointed at the third International Petroleum Congress at Bucarest, is now at work. Since the oils found in different fields differ in many respects it is necessary to adapt the method to local needs.

Preliminary Examinations.

Upon undertaking the examination of Kansas crude oils it was therefore thought advisable to make preliminary distillations in order to determine the temperature at which "cracking" or decomposition begins, and also to find out how to proceed in order to prevent cracking as far as possible.

Two samples of crude oil, No. 3, from Urbana, and No. 4, from Humboldt, were distilled under ordinary atmospheric pressure, from a half-liter distilling flask which was provided with two thermometers, one showing the temperature of the oil in the flask, the other the temperature of the vapors. The results are plotted in curves in the lower right-hand portion of plate XLI.

Small circles upon the curves mark the progress of the distillation. The horizontal distance to any given circle, measured from left to right, indicates the total percentage, by weight, of oil collected up to the time the observation was made. The vertical height of the same circle indicates the specific gravity, or density, of the portion collected at that time. The number of degrees noted adjacent to the circle shows the temperature, Centigrade, reached by the vapors when the portion was removed.

It will be seen that nearly 10 per cent. of gasoline having a specific gravity of about 0.75 was collected below 150° C. During the distillation of the kerosene, which includes all that portion of the oil which passes over from 150° to 300° C., the rise in temperature and increase in specific gravity is proportionate to the percentage of oil distilled. Beyond this point, however, the specific gravity of the distillate reaches a maximum of about 0.84 when about half the oil is distilled, after which the gravity decreases until more than 80 per cent. has been distilled. This is due to the fact that certain constituents of the oil are decomposed by the heat into simpler or lighter products, some of which are gaseous but most of which are liquids, and a small portion consisting of solid charcoal or coke. This process is technically known as "cracking," and many attempts have been made to employ the cracking process

of distillation in refining petroleum, because of the fact that the quantity of distillates corresponding in gravity to gasoline and kerosene is thereby increased. It has been found, however, that the cracked oils have a very disagreeable odor, become colored after standing for a short time, especially on exposure to air and light, and burn with a smoky flame. Furthermore, they require the use of too large quantities of sulfuric acid to refine them sufficiently to make them marketable. The yield of gasoline and of kerosene reported in the tables to follow do not include cracked products, and hence are not so large as the maximum amounts that might be obtained. Cracking began in the two oils examined when the temperature of the oil in the flask reached 350° C., and proceeded very rapidly at 400° C. Finally the thermometers were removed and distillation was carried on until the glass flask began to melt. During the latter part of the distillation the gravity of the products increased rapidly and the final distillate was yellow wax, of which about one or two per cent. was obtained. A residue of about 6 per cent of brittle coke was left in the flask.

Fresh samples of these oils were then distilled as before up to the point where the temperature of the vapors passing over reached 300° C. The condenser was then connected to a Brühl receiver and the pressure was reduced by means of a Chapman pump. Vacuum distillation is simply a process which enables us to distil substances about 100° or more below their boiling-points under ordinary atmospheric pressure. The oil began to distil over in the vacuum at 160°-170° C. The density of the fractions and the percentages of distillate increased proportionately to the rise in temperature until the oil in the flask reached about 350° C., when cracking began. By means of vacuum distillation, then, it is possible to distil without decomposition those constituents of the oil which range in density from 0.83 to 0.90. While distillation under ordinary atmospheric pressure yields only 33 per cent. of undecomposed products, vacuum distillation increases that yield to a total of about 65 per cent. The densities of the fractions and total percentages of distillate are shown in the curves, the points of separation between fractions being marked by small crosses. Vacuum distillation is sometimes employed in the refining of lubricating oils.

THE METHOD WHICH WAS EMPLOYED IN THE COMPARATIVE STUDY OF THE PROPERTIES OF KANSAS OILS.

About 0.7 liter of crude oil was weighed in a tared liter distilling flask and subjected to fractional distillation, the collecting vessels being changed at the following temperatures C.: 125°, 150°, 200°, 250° and 300°. In each case after first reaching the temperature at which a fraction was to be made the Bunsen flame was removed until the thermometer indicated a fall of 25°, when the distillation was renewed until the dividing temperature was reached a second time, after the method of Engler. Each fraction was weighed, and it was found that the loss of weight of oil in the flask exceeded the sum of the weights of the distillates. This difference in weight was due to the volatilization of the dissolved gases contained in the crude oil, and amounted to 0.3 to 1.5 per cent.

Distillation was then carried on in a vacuum, the pressure generally being reduced to that corresponding to 20 mm. of mercury. Fractions were collected at intervals of 25° C. The weight of the vacuum distillates was found to equal the loss of weight in the flask, showing that no appreciable amount of gas was formed through cracking.

The residue from the vacuum distillation was transferred to a half-liter distilling flask, which was supported on an iron stand and protected from drafts by two asbestos dishes placed vertically, one in front, the other behind, about half an inch from the walls of the flask. Heat was supplied by a triple burner, moderately at first, but finally the entire flask was surrounded by flame. The delivery tube of the flask was connected to an air-condenser. The receiver was provided with a side neck, through which the gases formed during cracking were passed either to a gasometer or to a Bunsen burner, where they were burned to get rid of their disagreeable odor. In general, the weight of gases and volatile products lost during the cracking process was approximately equal to the weight of the coked residue.

The samples of oil were collected in accordance with the directions of Professor Haworth, the state geologist, and every effort was made to have them truly represent the oil as it is obtained fresh from the wells. However, they were collected during the summer months, and it is probable that some of them, while exposed to the heat of the sun upon the platforms at the railroad stations and express offices, may have lost con-

siderable quantities of gasoline by evaporation. They were shipped in ordinary five-gallon cans, which were closed with cork stoppers. Recently a can of oil arrived at the University after having been delayed two weeks on account of the June floods, but apparently in good condition. Its gravity was 33.4° Bé. and it yielded 15 per cent. of gasoline. A sample shipped from the same well in March had a gravity of 36.9° Bé. and yielded 20 per cent. of gasoline. It will therefore be necessary to consider the possibility of variations due to this cause when comparing the results given in the tables that follow.

In attempting to compare oils of one field with those of another, it must be remembered that variations in the manner in which different experimenters carry out their distillations will cause differences in their results. Notwithstanding the errors thus arising, it seems desirable, especially in view of the fact that the prices paid for crude oils differ so much in different states, to compare the character of Kansas oils with that of oils from other fields.

In the upper left-hand portion of plate XLI curves are drawn so as to show the yield of gasoline and kerosene given by oils from important fields. The data regarding oils outside the Kansas field have been taken from publications already referred to elsewhere in this chapter. Temperatures are represented vertically and percentages of distillate horizontally.

The best yield is shown by Pennsylvania oil, which gives 20 per cent. of distillate boiling up to 150° C., which includes the gasoline, and about 60 per cent. distillate boiling below 300° C., which includes the kerosene. The next best oil is from Neodesha, Kan., which yields 17 per cent. gasoline and 47 per cent. oils boiling below 300° C. The third rank is taken by the oil from Findlay, Ohio, which gives a total yield below 300° C. equal to that from Neodesha, but it yields only 10 per cent. of gasoline, which is a little lower than the average of the sixteen gasoline-producing oils of Kansas.

The similarity between the oils of Kansas and of Ohio is further brought out by a comparison of the specific gravity and refractive index of the distillates.[257]

257. Bull. No. 282, U. S. Geol. Survey, p. 129.

Rank.	Fraction below 150° C. Field.	Gasoline and naphtha. Sp. gr.	Ref. index.
1	Pennsylvania	0.7188	1.415
2	Kansas	0.7220	1.408
3	Ohio	0.7297	1.412
4	Beaumont	Amount too small.	

Rank.	Fraction 150° to 300° C. Field.	Kerosene. Sp. gr.	Ref. index.
1	Pennsylvania	0.7984	1.437
2	Ohio	0.8014	1.442
3	Kansas	0.8038	1.445
4	Beaumont	0.8749	1.473

Rank.	Fraction 300° to 350° C. Field.	Heavy oils. Sp. gr.	Ref. index.
1	Pennsylvania	0.8338	1.462
2	Ohio	0.8404	1.468
3	Kansas	0.8460	1.470
4	Beaumont	0.9089	1.501

In regard to both quantity and quality of the most valuable product, gasoline, second place is held by Kansas.

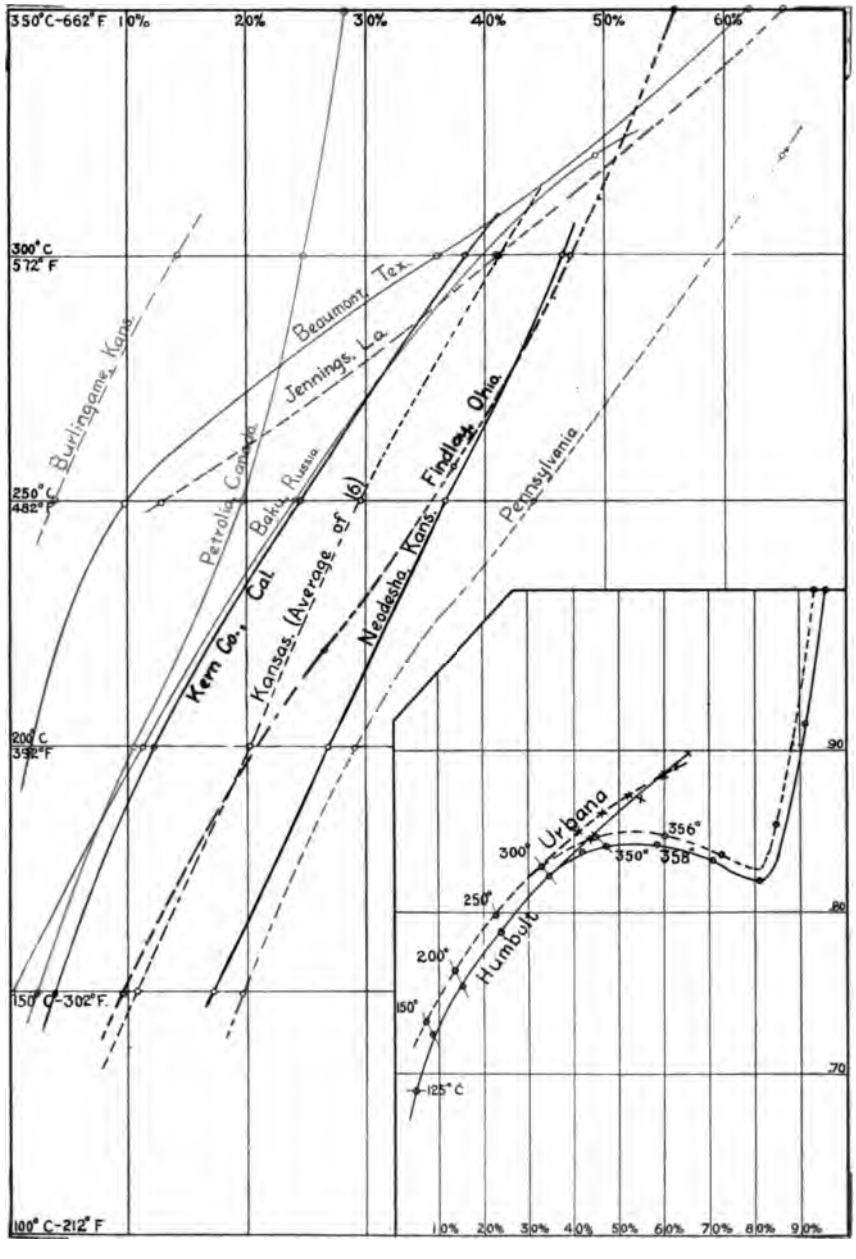
In regard to the quantity and quality of kerosene, second place must be yielded to Ohio, but the difference between the kerosene of Kansas and that of Ohio is very slight.

In the heavy distillates of Kansas the slight asphaltic nature is revealed. In this respect a relationship to the oils of the Gulf Coastal Plain seems to be shown. Nevertheless, the closer relation to the Eastern fields is shown by the fact that every one of the oils examined contained paraffin. In this connection I wish to quote from an article upon "The Petroleums of North America," by Clifford Richardson:[258]

"A typical Kansas oil of 0.8750 gravity, 30.0° B., received in 1901 from the Federal Gas and Oil Company, Cherryvale, Montgomery county, was examined by the writer, with the following results:

Specific gravity, 25/25°	0.873
Flash	32°
Volatile, 105°, 7 hours	21.4 per cent.
" 160°, 7 hours (fresh sample)	33.6 " "
" 200°, 7 hours (fresh sample)	47.9 " "
Character of residue at 200°	Soft.
Volatile, 160°, to constant weight	47.4 per cent.
Character of residue	Soft.
Volatile at 200°, to constant weight	59.4 per cent.
Character of residue	Soft-paraffin.

258. Jour. Franklin Institute, CLXII, 57, 81, 1906.



Character of different Petroleums.

DISTILLATION IN VACUO, 22 MM. PRESSURE.

Fraction.	P. ct. distillate.	Sp. gr. 20°.	Ref. index.	Remarks.
60- 80°	3.2	0.7637	1.425	Light straw-color.
80-100°	2.8	0.7683	1.428	" " "
100-120°	4.3	0.7814	1.434	" " "
120-140°	6.0	0.8008	1.443	" " "
140-160°	8.1	0.8209	1.454	" " "
160-180°	5.1	0.8382	1.462	" " "
180-200°	5.7	0.8489	1.469	" " "
200-220°	7.0	0.8608	1.475	" " "
220-240°	5.1	0.8911 (?)	1.482	Solid at 0° crystalline paraffin.
240-260°	6.2	boiled over.		do.
260-280°	12.5	" "		Rich in paraffin.
280-300	4.2	0.8963	1.498	Solid.

"The higher distillates in this oil separate paraffin and the residue is of a distinctly paraffin nature. The distillates correspond in character to those obtained from the Trenton limestone petroleum of Ohio, and show that the hydrocarbons contained in the oil must, in addition to the paraffins, consist of the same series found in the latter oil; that is to say, the C_nH_{2n-2} and C_nH_{2n-4} series.

"The residue from the distillation of Kansas oil reveals its mixed character by the paraffin scale which it contains and the higher fixed carbon which it yields."

SULFUR CONTENT.

About five years ago Bartow and McCollum called attention to the low percentage of sulfur contained in Kansas oils.[259] They found on the average 0.27 per cent. sulfur in the sixteen crude oils which they examined. The method which they used was that of Carius, which, though long and tedious, is of the highest accuracy.

In order to get some information regarding the sulfur content of the oils described in this chapter, Mr. Harvey G. Elledge and Mr. Wallace E. Pratt made some determinations by the briefer method of employing a Parr calorimeter bomb. They obtained the following results:

GASOLINE-PRODUCING CRUDE OILS.

Field No.	Location of well.	Gravity.	Sulfur.
3	Urbana	30.5° B.	0.38 per cent.
6	Moran	30.0° B.	0.43 "
12	Caney	32.8° B.	0.31 "
13	Peru (Alford well)	32.8° B.	0.32 "
14	Peru (Blundell well)	34.2° B.	0.27 "
15	Peru (town)	35.4° B.	0.48 "
16	Peru (Huffman well)	35.2° B.	0.27 "
19	Chanute	32.0° B.	0.34 "
	Average of eight wells		0.35 "

259. Loc. cit.

HEAVY CRUDE OILS.

Field No.	Location of well.	Gravity.	Sulfur.
9	South of Independence	23.7° B.	0.41 per cent.
10	Benedict	21.5° B.	0.50 "
18	Burlington	19.7° B.	0.76 "

DISTILLATES.

Field No.	Boiling-point.	Sulfur.
16	Below 200° C. atmospheric pressure	None.
16	200° to 300° " "	Trace.
14	150° to 300° " "	0.08 per cent.
14	160° to 250° 20 mm. pressure	0.23 "
14	250° to 300° 20 mm. "	0.45 "
14	Cracked oils	0.29 "
19	150° to 300° atmospheric pressure	0.023 "
19	250° to 300° 20 mm. pressure	0.38 "
19	Cracked oils	0.49 "

The heavy crude oil from Burlington, No. 18, is the only one that contains as much sulfur as the average of the Lima oils. Burlington is in the extreme northwest border of the Kansas field, and this oil is not of the same character as those marketed in the regions having pipe-line connections.

From all the data at hand it will be seen that the Kansas crude oils contain less than half as much sulfur as those of Lima, Ohio. The gasoline and kerosene distillates contain such small quantities of sulfur that special treatment for its removal is not necessary. The residues or "reduced oils" contain less sulfur than the fuel oils from the California or Beaumont fields.

TABLE No. 1. PROPERTIES OF THE CRUDE OILS.

Field No.	Location.	Density, 24° C.	Sp. gr. at 60° Fah.	Beaume 60° Fah.	Flash pt., Fah.	Burning pt., Fah.
5	Neodesha	0.8305	0.8378	37.1	Below 40°	Below 80°
8	Bolton	0.8340	0.8413	36.4	" 40	" 80
15	Peru (town)	0.8392	0.8465	35.4	" 40	" 80
16	Peru (Huffman)	0.8400	0.8473	35.2	" 40	" 80
14	Peru (Blundell)	0.8452	0.8525	34.2	" 40	" 80
17	Paola	0.8500	0.8573	33.3	" 40	" 80
12	Caney	0.8527	0.8601	32.8	" 40	" 80
13	Peru (Alford)	0.8527	0.8601	32.8	" 40	" 80
4	Humboldt	0.8548	0.8622	32.4	" 40	" 80
19	Chanute	0.8565	0.8639	32.0	" 40	" 80
7	Independence	0.8575	0.8649	31.9	" 40	" 80
1	Erie	0.8600	0.8674	31.4	" 40	" 80
2	Shaw	0.8610	0.8684	31.2	43°	115°
11	Coffeyville	0.8632	0.8706	30.8	Below 40°	95
3	Urbana	0.8648	0.8722	30.5	" 40	Below 80°
6	Moran	0.8675	0.8749	30.0	" 40	" 80
9	South of Independence,	0.9035	0.9110	23.7	265°	310°
10	Benedict	0.9170	0.9240	21.5	275	340
18	Burlington	0.9280	0.9340	19.7	194	275

TABLE No. 2. DISTILLATES, PERCENTAGE YIELD.

Field No.	Water.	Gasoline, to 150°, by vol.	Kerosene, 150°-300°, by vol.	Heavy oils.		Residue, by wt.	Loss, by wt.
				Vac. dis., by vol.	Cracked, by wt.		
5	.....	17.2	29.4	25.1	22.0	4 0	3.2
8	.....	16.3	32.8	22.2	22.2	4.8	3.8
15	.....	14.0	27.7	25.2	24 2	4.8	6.0
16	.....	13.4	29.7	25.4	23.3	3 7	7.6
14	1.2	11.9	29 4	25.5	25.0	5 7	4.1
17	.....	11.3	30.7	25.6	26 5	5.8	3.8
12	.....	9.0	33.6	28.3	22.7	4.1	5.1
13	0.9	10.3	29 6	25.4	24.4	5 2	7.3
4	.....	10.7	28.1	28.7	25.0	6.9	2.3
19	.....	8.7	31.4	28.1	27.1	3.4	3.4
7	.....	11.2	24.5	24.5	27.5	7.5	.....
1	.....	7.2	31.2	29.0	27.7	4.4	5.4
2	.....	5.6	34.1	29.9	26.9	4 2	3.5
11	7.3	7.3	27.4	25.1	23.1	6.2	7.5
3	.....	9.1	30.5	27.3	.....	4.6	.....
6	.....	8.9	27.7	25.3	28.8	7.5	.....
9	2.1	0.0	13.7	38.3	38.7	5.5	3.8
10	3.6	0.0	7.3	47.2	29.4	10.9	2.3
18	0.5	0.0	14.4	29.9	40.0	10 9	8.1

TABLE No. 3. SPECIFIC GRAVITIES OF DISTILLATES, IN DEGREES OF BEAUME'S SCALE.

	Gasoline.	Kerosene.			Heavy (vacuum) oils.				
Field No.	Below 160° C.	160° to 200° C.	200° to 250° C.	250° to 300° C.	Below 200° C.	200° to 225° C.	225° to 250° C.	250° to 275° C.	275° to 300° C.
	Below 302° F.	302° to 392° F.	392° to 482° F.	482° to 572° F.	Below 392° F.	392° to 437° F.	437° to 482° F.	482° to 527° F.	527° to 572° F.
5	65 3°	51.7°	45.0°	39.5°	35.3°	[31.7°	31.7°]	[28.7°	28.7°]
8	64.6	51.5	44.3	37.7	34 6	32.2	30.4	28 7	*
15	66.4	52.0	44.4	38.0	34 6	32.0	29.9	28.4	*
16	66.6	52.4	44 6	38.3	34.8	32.3	30.5	28 6	*
14	65.9	52.2	44 3	38.3	34 7	32 1	30.0	28.3	*
17	61.9	53 4	43.9	38.6	34.8	32.3	29 9	28 3	*
12	59.4	50 3	42.5	37.1	34.0	31.7	30 0	28.1	26.4
13	64.5	52 0	44 5	37.6	34 5	31.7	30.0	28.0	*
4	65 4	52 4	45.3	39 1	34 3	30.6	28.4	27.0	25.2
19	65.1	52 7	44 3	37.6	34.2	31.3	29.1	27 7	*
7	64.2	51 2	43 9	38.0	33.8	30 5	.....	27 7	25.2
1	61.4	53 0	44 4	37.6	33 8	31.1	28.8	27.6	25.7
2	61.0	52.5	44.3	37.4	33 5	30 5	29.0	27 4	26.1
11	61 7	51.4	44 9	38 5	34 0	31.1	29 8	28 0	25 1
3	61 0	50 6	42.7	36.9	34 0	31.6	29 5	27.7	*
6	61 6	50 2	43.2	37 1	33.1	[30 2	30 2]	[26.6	26.6]
9	none.	none.	none.	33.5	31 6	30 3	28.3	26 3	25 2
10	none.	none.	none.	32 3	29 3	[27.5	27 5]	[24 9	24.9]
18	none.	none.	39.9	36 5	32 9	30 2	28.4	26 6	24.7

Fractions marked * contained paraffin scale at room temperature.
When numbers in two columns are included in brackets the two fractions were mixed.

Optical Properties of the Distillates of Kansas Oils.

1. *Index of Refraction.* N 25/D.

The following table shows the index of refraction of the distillates as determined at 25° C. by means of an Abbe refractometer. The observations were made by Mr. Harvey G. Elledge:

Field No.	Kerosene distillates.			Vacum distillates.				
	150°–200°	200°–250°	250°–300°	170°–200°	200°–225°	225°–250°	250°–275°	275°–300°
5	.....	.....	.....	1 4691	.....	.....	.....	.....
8	1.4281	1.4468	1 4618	1 4704	1.4807*	.....	.....	.....
15	1.4260	1.4448	1.4607	1 4696	1.4767	1.4827	1.4888	.....
16	1.4258	1.4443	1 4594	1.4696	1 4757	1 4823	1 4878	.....
14	1.4262	1.4458	1.4594	1 4697	1 4763	1 4834	1 4886	1.4947
17	1.4234	1.4415	1 4785	1 4697	1.4772	1.4833	1 4894	1.4959
12	1.4292	1.4504	1.4636	1.4722	1.4787	1.4847	1.4913	1.4962
13	1.4271	1.4447	1.4607	1.4704	1.4776	1.4837	1.4896	1.4957
4	1.4239	1.4419	1 4579	1.4704	1 4851*	.....	1.4947	1.5008
19	1.4258	1.4451	1 4612	1.4612	1 4787	1.4868	1.4920	1.4977
7	1.4276	1 4455	1 4614	1.4712	1 4808	.....	1.4947†	.....
1	1.4245	1.4453	1 4608	1.4727	1 4801	1 4867	1.4951	1.4973
2	1.4259	1.4460	1.4641	1 4736	1.4806	1.4876	1.4933	1.4989
11	1.4282	1.4430	1.4589	1.4714	1 4767	1.4834	1 4907	1.4968
33	1.4221	1.4499	1.4629	1 4713	1.4787	1 4843	1.4918	1.4955
6	1.4296	1.4467	1 4632	1.4726	1 4834*	.....	1 4958†	.....
9	none.	none.	1.4693	1 4761	1 4857*	.....	1 4983†	.....
10	none.	none.	1.4717	1 4799	1.4904*	.....	1.5017†	.....
18	none.	1 4554	1.4634	1.4722	1 4797	1.4871	1.4939	1.5000
Average	1.4268	1.4454	1.4610	1.4717	1.4780	1.4847	1.4913	1.4972

*200°–250°. †250°–300°.

It is the opinion of the writer that the index of refraction of the petroleum distillates, considered in connection with their specific gravity and boiling-point, will be a very valuable aid as an indication of the predominating hydrocarbons that are present. Only a few investigators have reported this constant. Since the determination is so readily made, one drop of oil being a sufficient quantity, it is hoped that observations may be hereafter reported from every oil-field. The index of refraction of such pure hydrocarbons as have been isolated is generally determined, and in some cases also that of the distillates from which they were obtained have been reported. Comparison of data from fields that have been thoroughly investigated chemically with the preliminary data from new fields will undoubtedly be of much value.

2. *Rotation of the Plane of Polarization of Light.*

The optical properties of the distillates were not examined until nearly two years after the distillations had been made.

The higher fractions had become so highly colored as to render them opaque for examination in the polariscope. A few of the lower and clearer fractions upon preliminary examination gave indications of slight optical activity. In order to thoroughly test the matter, the vacuum fractions of oil No. 3, from Urbana, which we had in largest amount, were redistilled and the fresh, slightly yellow colored samples were then examined in the polariscope by Mr. Frank Brock, with the following results:

Boiling-point.	Sp. gr. 25°-15°	Ref. index.	Optical rotation in a 200 mm. tube.
195° at 88 mm. to 215° at 86 mm.	0.8454	1.4709	0.10° to the right.
215° at 86 mm. to 228° at 87 mm.	0.8503	1.4738	0.11° " "
228° at 87 mm. to 239° at 87 mm.	0.8530	1.4754	0.15° " "
239° at 87 mm. to 250° at 92 mm.	0.860	1.4769	0.235° " "
225° at 35 mm. to 237° at 30 mm.	0.867	1.4828	0.34° " "
237° at 30 mm. to 248° at 30 mm.	0.872	1.4859	0.465° " "
248° at 30 mm. to 257° at 30 mm.	0.875	1.4876	0.54° " "
250° at 28 mm. to 262° at 28 mm.	0.879	1.4895	0.61° " "
262° at 28 mm. to 272° at 27 mm.	0.881	1.4909	0.76° " "
272° at 27 mm. to 282° at 27 mm.	0.883	1.4920	0.98° " "

The same pronounced optical activity in the higher-boiling fractions has been recently observed in Roumanian petroleum[260] and petroleum of the Ferghana district, Russia.[261] By means of this optical activity chemists may be enabled to detect small quantities of certain constituents of the oils, and gain information regarding certain changes which these constituents are capable of undergoing.

Notwithstanding the fact that petroleum has been marketed in vast quantities for many years, little use has been made of it except for fuel, illumination or lubrication. Coal-tar, which resembles petroleum in many respects, was formerly considered valueless, but now finds use as the raw material from which a very great variety of industrial products are being manufactured. The development of these industries came only after the researches of scientists had revealed the presence of constituents previously unknown. Crude petroleum contains different classes of chemical substances that have never yet been studied sufficiently to enable us to make use of them. There may be great difficulties to overcome before processes for the utilization of these constituents can be developed, but the history of the progress of chemical industries in the past leads us to believe that when these difficulties are overcome far-reaching benefits of permanent value will be the result.

260. Reinhard and Botez, Revue du Petrol, 1908, 10.

261. Rakusin, Revue du Petrol, 1908, 146.

CHAPTER IX.

COAL MEASURES FAUNAL STUDIES: FAUNAL DIVISIONS OF THE KANSAS COAL MEASURES.

J. W. BEEDE and AUSTIN F. ROGERS.

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THE CHARTS.

Introduction.

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CHAPTER IX.

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J. W. BEEDE and AUSTIN F. ROGERS.

INTRODUCTION.
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COLLECTIONS.
NOMENCLATURE.
THE FAUNA.
THE CORRELATION VALUE OF SPECIES.
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FAUNAL DIVISIONS.
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  - Stage A.
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There have been two results of the study of the material secured: First, the demonstration of sufficient faunal differences to warrant the establishment of a number of distinct faunal groups of the rank of stages, which was the immediate object of the undertaking; second, the revelation to us of many problems of distribution and morphologic characters of the fossils, which must be worked out before the fauna as a whole can be comprehensively known. This paper deals largely with the first of these results.

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limestone this outer layer almost invariably peels off, giving the shell the appearance described by Shepard. This feature is more strongly characteristic of this species than of any other we have met in the Coal Measures rocks. It should also be stated that, judging from the locality from which they were taken, there is very strong probability that Professor Shepard's specimens were broken from limestone. So far as Shepard's figure is concerned, it is not so accurate as those employed by paleontologists at the present time, and, dissociated from the description, could not be applied to any species with certainty. In the light of these considerations we feel it is but just to ascribe the description to this species, which it certainly characterizes in an uncritical way and is the first description of it. It is so well known that no confusion need follow the change.

Reticularia perplexa (McChes.) has been referred to the genus *Squamularia* of Gemmellaro, inasmuch as the hinge structure differs from that of *Reticularia* and agrees with that of Gemmellaro's genus, according to Doctor Girty.[269] *Chonetes granulifer* Owen was recorded from the Cherokee shales in one of our previous lists. Since then Mr. F. C. Greene has worked out its development and range and found that the Cherokee shales specimens belong to a distinct but closely allied species. *Schizodus circulus?* is in all probability the young of an unknown species. *Echinocrinus agassizi* Hall, of the previous lists, is *E. aculeatus* Shum., but the figures by Keyes are not typical of it. Since the bulk of the paper was written and the charts made out, Bather[270] has shown that the term *Archæocidaris* was antedated by *Echinocrinus* of Agassiz, and will have to be replaced by it. The change is made in the lists following. *Chonetes flemmingi* is changed to *C. variolatus*. *C. geinitzi* is substituted for *C. glaber*. *C. lævis* Keyes is a distinct species of very different range.

The genus *Bellerophon* has been divided into several genera. Our species fall under the heads *Bellerophon, Bucanopsis, Euphemus* and *Patellostium*. The genus *Pleurotomaria* has been subdivided and the species are referred to the proper genera so far as they have been worked out. The genera under which our species fall, aside from those temporarily referred to the original genus, are *Euconospira, Phanerotrema, Trepospira* and *Worthenia*. *Nuculana bellistriata attenuata* Meek is

269. Op. cit., pp. 387-392.

270. Ann. and Mag. Nat. Hist., ser. 7, XX, Nov., 1907, pp. 452-456.

here elevated to the rank of species. The two, the variety and the species, are associated in the lower rocks, but the "variety" replaces the species in the upper rocks. The little shell is so characteristic of the whole Kansas section that it is worthy of specific rank without question. The fossil provisionally identified as *Seminula subquadrata* Hall, from the Pawnee limestone, is a worn, imperfect specimen of questionable identity. It may be the same species as that identified by Doctor Bennett as *A. trinucleus* from this horizon.

The Fauna.

The fauna as a whole is made up as follows:

Foraminifera, 12 species.
Spongiæ, 5 species.
Anthozoa, 10 species.
Crinoidea, 28 species.
Ophiuroidea, 1 species.
Echinoidea, 8 species.
Vermes, 2 species.
Bryozoa, 47 species.
Brachiopoda, 46 species.
Pelecypoda, 111 species.
Scaphopoda, 1 species.
Gastropoda, 51 species.
Pteropoda, 1 species.
Cephalopoda, 26 species.
Trilobita, 3 species.
Ostracoda, 15 species.
Merostomata, 7 species.
Insecta, 13 species.
Vertebrata, 13 species (in the chart. Plate XLII).

While the brachiopods are fourth in the list with respect to the number of species found, nevertheless the fanua as a whole is distinctly a brachiopod fauna, so far as the number of specimens to be noticed are concerned. While the pelecypods contribute nearly a third of all the invertebrate species to the fauna, yet, with few exceptions, they form but a very small percentage of the specimens of any faunule. The *Mollusca* contribute practically half the species found, though rarely can a faunule be said to be molluscan. It is not until near the top of the section is reached that the *Mollusca* finally assume supremacy over the *Brachiopoda,* never to relinquish it.

Aside from the *Fusulinæ* the *Productidæ* contribute more to the make-up of the faunules than any other family. After the *Productidæ* come the *Spiriferidæ* and the *Athyridæ* as chief causes of the faunal coloration.

The Correlation Value of Species.

For purposes of correlation certain species are of much more value than others. The ones of greatest value are those of wide distribution and short range, as *Chonetes mesolobus,* N. and P., *Chætetes milleporaceous* M., E. and H., *Schwagerina princeps* (Moell.) and others. With the exception of certain limitations mentioned later the chart shows what species are

the most valuable for this purpose occurring in the Kansas rocks. Even a glance at the chart will also show that there are certain species which are of no practical value for such purposes, as *Seminula argenteia* (Shep.), *Productus semireticulatus* Mort., *Derbya crassa* Meek, *Meekella striaticostata* (Cox), and others. The unfortunate thing about it is that only these vigorous species are the first to invade a new territory and sometimes occupy it practically to the exclusion of others. It may also happen that the time during which favorable conditions exist in a region is so short that only the more vigorous species succeed in entering it.

An interesting example of this is afforded in the Ames limestone of West Virginia. Many of these hardy species broke into this region at that time, while but few of the weaker ones succeeded in reaching it. For this reason it is very difficult to correlate this limestone accurately with the Kansas rocks.[271]

Aside from the two classes of fossils just mentioned there is a third class which is of considerable value for purposes of correlation in a broad way. Such species as *Chonetes granulifer* Owen, *Aviculopecten interlineatus* M. and W., *Cleiothyris orbicularis* (McChes.), and others, do not characterize any narrow horizon or even stage, but do characterize the larger groups of a period in such a way as to be of considerable value in making broad correlations, especially intercontinental ones.

It should be remarked in this connection that there are cases where the chart is known to be incomplete. For instance, Meek describes several species from the strata at Nebraska City, Neb., which are not recorded from the rocks supposed to be their equivalent because of the lack of positive correlation, the idea being to avoid possibilities of error, in so far as may be possible, in assigning species to horizons. Again, a species may seem to have a very wide range in other regions and a very restricted one in the Kansas rocks. This is capable of at least two interpretations—first, that it only had access to the Kansas sea for a very short time, and after retreating during some time of unfavorable conditions was unable to return; and second, that it is present and has not been found. Then, there are species which are known to have a wider geologic range than is shown on the chart but are not known from exact horizons. It is deemed better not to attempt to show

271. Geol. Surv. W. Va., Rep., 1906, pp. 127-130, 1907.

their range in such cases than to chance an error in doing so. The spaces on the chart may be filled in easily enough when the additional range is certainly known, but to ascribe a species, in a chart of this kind, to a horizon where it does not occur, is apt to become a permanent error.

Another point of some significance which may be determined by the chart is the time at which migrations of individual species is most apt to occur. It is well understood that the most vigorous species, represented by large numbers of individuals, are the ones that migrate most readily, other things being equal, and form the cosmopolitan elements of the faunas of the various periods. They are frequently characterized by their great stratigraphic range, which is in accord with their hardiness.

In the life-history of many species there is a time when it is more vigorous and found in much greater abundance than at any other time, even though it may be found throughout a very considerable range of strata. This period in the existence of a species is usually referred to as its culmination. Other things being equal, it is believed that a species is more apt to withstand the vicissitudes of migration at this time than at any other on account of its greater numbers and reproductive ability and greater vitality. Of course its migration at any time is governed largely by its opportunities to do so, as the reduction of barriers and extent of continental shelf, currents and food supply. It is believed that this feature is of sufficient importance to be taken into account in making the broader correlations, especially if there is evidence that there was a possibility of migration from the home basin at a time within such culmination. It is further believed that the influx of a considerable faunal element into a region is sufficient evidence of the equal opportunity for the inhabitants of a basin to emigrate.

On the continental shelves of such oceans as the Pacific, especially where there is great instability of conditions and opportunity for great intermigrations, the chance for a species to complete a life-cycle in any geographical province is small, as has been pointed out by Prof. J. P. Smith.[272] In such cases species appear and disappear rapidly, according as they are forced out by the arrival of more vigorous species from other regions or by orographic movements. On the other

272. Jour. Geol., vol. III, pp. 486, 487, 1895.

hand, the faunas occupying the epicontinental seas for great lengths of time were protected from both these influences, and as a consequence led a more peaceful and longer existence, permitting the study of their characters through a much greater length of time. The recognition of these principles, if they be correct, is of double significance in correlation.

There is small difficulty in recognizing the relative stages in the life-history of a species, especially of brachiopods, to one familiar with them, and they are an indication of the time when the migration into a region took place if the specimens of a species are all from a single stage of the life-history. If these features are not recognizable there is then more or less probability that the migration took place during culmination. For example, *Squamularia perplexa* (McChes.) is so abundant in the Pawnee and Altamont limestones as, locally, to contribute very largely to the formation of the stone. Specimens of it are fairly abundant until the Oread limestone is passed, when it becomes rarer, and finally disappears in the Howard limestone. The earlier specimens are smaller than the later, which are large, thick-shelled, and show the characteristics of old age. It is believed that in such cases as this the species is much more likely to perform migrations in its earlier stages of existence than in its later stage, with its senile characters and rare occurrence.

Faunal Distribution.

Space will permit but a mere mention of the more striking features of the distribution of the species of the faunules of the various horizons, which are more complicated than one would expect. This distribution was probably profoundly influenced by the presence of a varying shore-line to both the southeast and east of much of this area, while to the south of the younger, or western part of the section, shallow water or occasional beach conditions occurred on the south in Oklahoma.

These last conditions continued long into the Permian and produced a rather marked change in the fauna of the southern end of the upper horizons in tending to retain some of the shallow-water species after they had disappeared from the northern part of the region. The conditions affecting the northeastern and eastern faunas discussed below were probably those incident to the coast of any very shallow epi-

69. Sponge sp.
70. Enteletes h
71. Sponge sp.
72. Pinnatopora
73. Aulopora?
74. Lophophyll
75. Polypora tr
76. Chonetes g
77. Derbya beni
78. Derbya keol
79. Pugnax uta
80. [illegible]
175. Peripristis s
176. Worthenia
177. Astartella v
178. Prismopora
179. Pugnax rock
180. Phanerotren
181. Chonetes gr
182. Euphemus
183. Aviculopinna
184. Trachydomia
185. Edmondia r
186. Aviculopecte
187. Metaceras
188. Orbiculoidea
189. Pinna perac
190. Lima retifer
191. Solenomya
192. Pinnatopora

abundant only in the northern section at Lawrence and Lecompton. In the case of the last-named species its lack of occurrence at Burlington is probably due to the fact that the bituminous shales below the upper Oread were not exposed there.

The collections from Stage G and the base of Stage H are all from the Kansas river region.

The Emporia limestone has more of a molluscan fauna at Emporia than its equivalents on the Kansas river. *Aganides* sp., *Gastrioceras* sp., *Pleurotomaria perhumerosa* Meek, and another gastropod and *Nuculana attenuata* Meek are fairly abundant at Emporia.

The fossils from the Americus limestone recorded here were taken from the type locality only, as doubt exists as to its equivalent on the Kansas river.

The Neva limestone is nearly unfossiliferous in the northern part of the state, and the most of the fossils recorded for it were collected from near Hooser, Cowley county.

The Florena shales present a somewhat different faunal assemblage in the southern region from what they do at Cottonwood Falls and Florena. The sediments are less calcareous and the differences in the fossils consist largely of the dilution of the northern fauna by the addition of other species from the rocks below. At Grand Summit the part played by senile seninulas, chonetes and derbyas is relatively less, while fusulinas and other species become much more abundant. The list increases from about thirty-five species in the north to seventy-three at Grand Summit. Nineteen of these species are represented in our collections by from 30 to 500 specimens each from an exposure of about a square rod at Grand Summit.

The remarks concerning the general faunal character of the Florena shales are doubly applicable to the Neosho formation. It increases from about thirty species in the northern part of the state to ninety in the southern part. In the former region the specimens are, relatively, as rare as the species. In the southern region the older species found a more favorable environment, and many which had disappeared in the northern region persisted in this part of the sea so that the exposure at Grand Summit has many reminders of Meek's classic "Nebraska City Section," though it is much higher in actual horizon.

Some of the more striking features of the southern region

continental sea located within a region of subdued topography, causing local shifting and occasional, in this instance rhythmical, wider shiftings of faunas to regions without the bounds of the state. These greater movements were several times accompanied by a breaking down of barriers for a short time, allowing new faunal elements to enter the Kansas basin. The present state of our knowledge is not such as to permit of a clear understanding of the extent and true significance of these changes.

The faunules to be considered in this paper are mainly those of the limestones. The species of the intervening shales are different from those of the limestones but are considered to be contemporaneous with them, though they occur in sediments deposited immediately beneath or upon them. They represent faunas coexisting in adjacent regions under different conditions of sedimentation, the shale faunas merely shifting into a region when the muddying of the waters either caused the existing fauna to retreat or smothered it. On account of the lack of good exposures and the paucity of the shale faunas the limestone faunas are much better known.

Throughout this field there is a closer and more interesting relation between the character of the faunules and the nature of the deposition among the limestones themselves than there is between the limestones and shales. In impure, marly layers, certain species are found more abundantly than elsewhere. White pure limestones contain a somewhat different fauna from impure ones, etc. The heavy oölites are characterized by a strong molluscan fauna with a proportionally small brachiopod fauna. In this way the limestones of Stage C present a very different appearance at Kansas City from what they do in southern Kansas, though there is no doubt of their continuity. As will be seen below, the faunal differences found in a formation are quite as striking as are the variations of its lithological phases.

The Bethany Falls limestone is the lowest of the formations common to the Kansas river region in Kansas and the Neosho river or southern Kansas region. From a single locality at Erie we have over 400 specimens of *Lophophyllum westii* Beede, while extensive collecting from this horizon at Kansas City and Pleasant Hill, Mo., have failed to reveal a specimen of it. For this reason it has been necessary in constructing the chart to represent as abundant species which may not be

found in the same horizon a considerable distance away. *Fusulinella?* sp. is quite common locally at Kansas City and wanting at Erie. *Chonetes verneuilanus* N. and P. is much more abundant at Kansas City than at Erie, as is *Dielasma bovidens* Mort. and *Axophyllum rude* W. and St. J. *Marginifera longispinus* (Sow.?) is moderately abundant at Kansas City and extremely so at Erie. Fifty-seven of the species recorded from this horizon are not common to the two localities. The whole pelecypod and cephalopod fauna is wanting at Kansas City, as are most of the gastropods. Molluscs and corals seem to abound in the southern locality and not in the northern.

In the Mound Valley limestone five of the species of importance at Erie are wanting at Kansas City. They are *Myalina subquadrata* Shum., *Polypora elliptica* Rog., *Stenopora carbonaria* (Worth.), *Productus pertenuis* Meek, and *P. cora* d'Orb. This horizon does not appear to be very fossiliferous at Kansas City, but fourteen species being found there, while three times as many occur in it near Erie.

The fauna recorded from the Galesburg shales is from Kansas City.

The Dennis limestone has a very different appearance at Kansas City from what it has on the Neosho river. At the former locality it is dark and cherty, while in the southern region it is very light colored and sometimes slightly oölitic. The faunal differences are quite as great as the lithologic characters. Of the sixteen species of numerical importance from this formation only six occur at Kansas City. Two of these are not found on the Neosho river—*Schizodus wheeleri* Swall., and *Bellerophon percarinatus* Conrad. The remaining ten are mostly brachiopods, largely *Producti.* They are *Squamularia perplexa* (McChes.), *Productus punctatus* Mart., *P. pertenuis* Meek, *P. costatus* Sow., *Proboscidella* sp. and *Spirifer cameratus* Mort., and three Bryozoa, *Stenopora carbonaria* (Worthen), *Rhombopora* sp., and *Cystodicta inequimarginata* Rog. Of the whole fauna of this limestone only about twenty per cent. (seventeen species) of them are common to the two regions. The coralline fauna, together with nearly all the *Bryozoa,* fourteen species of brachiopods, twelve species of pelecypods, four gastropods and a cephalopod, are confined to the southern region, while one bryozoan, three brachiopods, twenty-two pelecypods, three gastropods and ten cephalopods are known only from Kansas City. It will be seen that the

southern aggregation is coralline-molluscoidean and the northern decidedly molluscan.

The fossils from the Drum limestone were all taken from the Kansas City region (Kansas City oölite). The Kansas City oölite is treated in this paper as a continuation of the Drum limestone of the southern part of the state. On account of the rapid thickening and thinning of the Drum limestone, which is semioölitic, this is not certain. Whether it is continuous or not, it occupies a position between the Dennis limestone and the Iola limestone and can thus be taken as its stratigraphic equivalent. Since all the fossils noted from this limestone are from the Kansas City region, no confusion need arise from this usage.

The distribution of the Iolan species is much more regular than those of the preceding stage. The lithologic characters of the rock are regular, indicating about the same conditions of deposition over a wide area. The Kansas City region has furnished over ninety species from this limestone, while less thorough collecting from Iola has revealed over sixty. The bryozoan and crustacean fauna seems much larger at Kansas City, perhaps due to the more thorough collecting. In other respects the fauna is not dissimilar, save in the case of a few individual species. *Cryptacanthia compacta* W. and St. J. and *Meekella striaticostata* (Cox) are abundant at Iola and Chanute and wanting at Kansas City. The reverse is true of *Aviculopecten carboniferus* Stev., *Rhombopora lepidodendroidea* Meek, *Cypridella* sp. *Chainodictyon laxum* Foerste, *Fenestella remota* Foerste, and *Cyclus communis* Rog.

The strong sponge fauna of the Allen limestone seems to be confined to the region of the Neosho and Verdigris rivers, while the Kickapoo limestone and its peculiar fauna has only been studied in the northern part of the state.

The peculiarities of the Oread fauna are in part due to more thorough collecting in the northern region and in part to the fact that the lower limestone was not seen in the southern section. The sponge fauna seems to be confined to the southern region. Sixteen species of *Bryozoa* and twenty-two species of pelecypods are not found in the Burlington collections, and a sponge and *Stenopora carbonaria* (Worth.) are abundant and known only from the latter locality. *Aulopora? prosseri* Beede, *Polypora triangularis* Rog., *Rhombopora lepidodendroidea* Meek, and *Orbiculoidea missouriensis* (Shum.) are

abundant only in the northern section at Lawrence and Lecompton. In the case of the last-named species its lack of occurrence at Burlington is probably due to the fact that the bituminous shales below the upper Oread were not exposed there.

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Some of the more striking features of the southern region

FIG. 1. The Cottonwood limestone at Grand Summit. The three thin white layers at Prof. Yates's feet, and the Florena shales above.

FIG. 2. Horizon of the fossil vertebrates south of Dexter, Kan. In the well by the buggy where the lines would meet Wreford limestone forms escarpment on either side.

FIG. 3. Cottonwood limestone at Beaumont, in three layers, with over and underlying shales. Part of Plate XLIII.

are the ophiuroids (rare); the culmination of *Productus nebraskensis* Owen, nearly a thousand specimens of which are in our collection from a single stratum at Grand Summit; the abundance of an undetermined species of *Schizodus* and the culmination of *Thamniscus octonarius* Ulrich, which is present in thousands at Beaumont. The pelecypod and gastropod elements in this faunule are very strong in this region, as are the octracods. *Derbya multistriata* (Meek) becomes very abundant for the first time, and there is almost a total absence of *Seminula argentea* Mort., *Chonetes granulifer* Owen, and *Productus nebraskensis* Owen, which make up a very large percentage of this fauna in the northern region.

Faunal Divisions.

The study of the faunal characteristics of the Kansas Coal Measures has given rise to certain unexpected questions of nomenclature in a larger way, and the results are hardly in accord with the general impressions of the subject.

The division of the rocks into two groups, characterized by both faunal and economic features, hardly fits the Kansas conditions. They fall rather into four divisions which are

very closely related. In some respects the lower two divisions are more closely related to each other than to the two upper ones. It is not improbable, too, that the uppermost one may prove to be quite as closely related to the Permian as to the Coal Measures.

In this connection the question naturally arises as to what are Upper and what are Lower Coal Measures? Some of the species usually regarded as characteristic of the Lower Coal Measures are largely confined to the rocks below the Bethany Falls limestone. *Prismopora triangulata* White, *Chonetes mesolobus* N. and P. and *Fusulinella* are examples. The first two of these are of especial importance. Other species occur here which continue to the top of the Iola limestone but are not found above it. Among these are *Cryptacanthia compacta* W. and St. J., *Lima krotowi* Stuck., *Cleiothyris orbicularis* (McChes.), *Strophalosia spondyliformis* W. and St. J., *Aviculopecten rectilaterarius* Cox, etc. In the light of these facts and that *Enteletes hemiplicata* Hall, *Chonetes granulifer* Owen,[273] and the species *Fusulina*, are either totally absent or very rare in and below the Iola limestone, and that they are all considered typical Upper Coal Measures fossils, the top of the Iola might be considered as the limit of the Lower Coal Measures.

However, there are certain differences between the two lower divisions tending to sharply separate them. There are several important species introduced into the basal part of Series II which implies also a decided change in the geographic conditions at that time. These fossils are discussed below.

It has been the custom of this Survey to refer to the rocks below the Bethany Falls limestone as Lower Coal Measures. In this case they would be coincident with Series I so far as the Kansas rocks are concerned. Inasmuch as the faunal grouping and the geologic history of the rocks lends itself so well to this classification we see no objection to the continuation of the custom. However, the Lower Coal Measures of Kansas must not be confounded with the basal Coal Measures of other countries or even of other regions in the United States. The unconformity between the Mississippian and the Coal Measures as represented in southeastern Kansas is a profound one, and it is probable that a very large part of the missing record belonged to the rocks above the Mississippian. In Arkansas and eastern

273. Doctor Bennett records a specimen of this species from the Bethany Falls limestone. However, it is extremely rare below the Lane shales.

Oklahoma are great thicknesses of rocks referable to the Coal Measures which underlie the "Lower Coal Measures" of Kansas, so that, in a broad sense, our Lower Coal Measures may turn out to be the basal part of the Upper Coal Measures or the top part of the Lower Coal Measures.

A careful inspection of the charts shows that they fall into groups which mark off salient periods in the geologic history of the region. The faunal assemblages are distinctive when studied with respect to the relative abundance of their species and the part they play in the older and younger formations, together with the introduction of new species and the disappearance of old ones.

One other feature is of interest here, and that is that when an influx of new species is noted in any limestone there is frequently a final disappearance of some of the older residents of the region after passing that particular limestone. The Iola limestone is a good example of this condition of things, which tends to complicate the establishment of sharp division lines.

As a result of the study of the fauna as a whole the following larger and smaller faunal divisions have been made out.

In order to show the relation of this classification to the purely stratigraphic (or, better, physiographic) one employed by this Survey and classifications used by other organizations and individuals we give the following tabulation.

COAL MEASURES.	SERIES IV.	STAGE J.	Neosho formation. Fluvena shales. Cottonwood limestone.
		STAGE I.	Eskridge shales. Neva limestone. Elmdale formation.
	SERIES III.	STAGE H.	Americus limestone. Admire shales. Emporia limestone. Willard shales. Burlingame limestone. Scranton shales.
		STAGE G.	Howard limestone. Severy shales. Topeka limestone. Calhoun shales. Deer Creek limestone. Tecumseh shales. Lecompton limestone. Kanwaka shales.
		STAGE F.	Oread limestone. Lawrence shales. Kickapoo limestone. Le Roy shales. Stanton limestone. Vilas shales. Allen limestone. Lane shales.
	SERIES II.	STAGE E.	Iola limestone. Chanute shales.
		STAGE D.	Drum limestone.
		STAGE C.	Cherryvale shales. Dennis limestone. Galesburg shales. Mound Valley limestone. Ladore shales. Bethany Falls limestone.
	SERIES I.	STAGE B.	Pleasanton shales. Coffeyville limestone. Walnut shales. Altamont limestone. Bandera shales. Pawnee limestone. Labette shales. Fort Scott limestone.
		STAGE A.	Cherokee shales.

Stages A and B correspond with similar divisions proposed by Professor Haworth,[274] based upon lithologic and topographic features. The Pottawatomie formation there described falls into Stages C, D, E and part of F. The Douglas is represented by the upper part of Stage F, the Shawnee by Stage G and the basal part of H. The Wabaunsee Stage is largely represented in Stage H, which should retain the name Wabaunsee, in the opinion of one of the writers. The remainder of the stage is found in Stage I. The three upper formations are grouped under Stage J, which is exactly equivalent to Prosser's Council Grove Stage, which should stand.

In the "Bulletin on the Economic Geology of the Independence Quadrangle," the United States Survey proposes a series of overlapping or interlocking formations which include parts of each other in a confusing way. Some of the limestones play out, one here and another there, in the southern part of the state. Where a limestone disappears the overlying shale and the underlying shale are grouped together under a formation name. Another one next to these disappears later and the three shales are given a third term. This seems to have been the general scheme followed, and the result is shown in the left column in the last tabulation.

It will be noted that there is a general correspondence between Series I, II and III and the old classification of Lower, Middle and Upper Coal Measures, though there is no inclination on the part of the writers to make such a substitution.

SERIES I.

The first grand division of the Coal Measures rocks with respect to the enclosed fossils extends from the base of the Cherokee shales to the base of the Bethany Falls limestone. There are at least twelve species which are at present unknown outside these rocks in the Kansas section, though some of them appear to have greater range in other regions. They include five cephalopods; *Asymptoseras newloni* Hyatt, *Domatoceras umbilicatum* Hyatt, *Temnocheilus crassus* Hyatt, *T. depressus* Hyatt, and *T. latus* Hyatt; one gastropod, *Aclisina minuta* Stev.; one pelecypod, *Conocardium acadianum* Dawson; two brachiopods, *Chonetes mesolobus* N. and P., and a species of *Seminula*. Species of the genus *Prismopora* are unknown except in these rocks. Aside from these our collections do

274. Vol. III, this Survey, p. 94, 1898.

not contain *Pleurotomaria scitula* M. and W., *Petrodus occidentalis* and *Clinopistha radiata* Hall? from higher horizons.

Among these species *Chonetes mesolobus* N. and P. and *Marginifera muricata* N. and P. are of great importance. The former is characteristic of nearly the whole section and unknown above it, and the latter is the preponderating species in the Cherokee shales and is more or less common throughout Series I, but is very rare in the succeeding stages. Series I may well be characterized as the *Chonetes mesolobus* zone. *Fusulinella* is also an important element in the fauna of these rocks although never so abundant as *Fusulina* in the upper rocks. In southern Kansas it is confined to the strata below the Bethany Falls limestone, but at Kansas City *Foraminifera* occur in the Bethany Falls limestone, possibly belonging to this genus. Especially in the Pawnee and Altamont limestones, *Squamularia perplexa* (McChes.) is frequently extremely abundant and is usually smaller in size than specimens from considerably higher horizons. It culminates in these limestones. *Chætetes milleporaceous* M.-E. and H. forms reefs in the upper Fort Scott limestone and is very abundant in the Pawnee limestone. It is similar in these respects to the occurrence of *Chætetes* at Bend, Tex., though the masses are somewhat smaller. Similar conditions exist in rocks of the same or nearly the same horizon at Doran siding, east of Holden, Mo., where the creek crossing the railroad has exposed a considerable area of the limestone.

As would necessarily be the case, inasmuch as the Kansas section begins with the Mississippian Coal Measures unconformity, the rocks of Series I were characterized by the introduction of the typical Coal Measures species. Sixty-three of the 111 species which become numerically important were introduced before its close, and twenty-five of them attain prominence before the close of the epoch.

Stage A.—Series I consists of two well-defined faunas, those of Stages A and B. The fauna of Stage A is confined to the Cherokee shales, and is characterized by the dominance of *Marginifera muricata* (N. and P.) over all other species, and may be referred to as the *Marginifera muricata* zone, although it extends well into the formations above. In our collections the five cephalopods mentioned above are confined to it, as is *Aclisina minuta* Stev. The principal characteristic of the stage is the absence of the species playing important roles in

the succeeding faunas, only 26 or 28 of the 111 being found. *Fusulinella* is absent from the Kansas rocks, though it is present in strata apparently of the same horizon at Knobnoster, Mo.

Stage B.—This stage is composed of the Fort Scott limestones, Labette shales, Pawnee limestone, Walnut shales, Coffeyville limestone and Pleasanton shales. During this stage barriers were broken down and a great influx of species occurred. Sixty species are introduced in the Fort Scott limestone, many of which play important parts during the succeeding epochs, and fifteen species are added during the remaining formations. The species which were quite abundant in this stage and not in the succeeding ones are *Squamularia perplexa* (McChes.) and *Fusulinella* sp. *Marginifera muricata* N. and P., *Cypridella americana* Rog. and *Griffithides scitula* M. and W. become moderately abundant only in rocks of this age. With the exception of *Marginifera muricatus* (N. and P.), all the species may be said to culminate in Stage A. *Chætetes milleporaceous* forms such a striking feature of it that it may be designated the *Chætetes milleporaceous* zone.

Of the species not mentioned, *Productus semireticulatus* Mart., *P. punctatus* Mart., *P. pertenuis* Meek, *Spirifer cameratus* Mort., *Marginifera longispinus* (Sow.), *Axophyllum rude* W. and St. J., become abundant for the first time in the Fort Scott limestone. The following species first come into prominence in the Labette shales: *Derbya crassa* (M. and H.), *Orbiculoidea missouriensis* (Shum.), *Productus cora* d'Orb., *Nucula ventricosa* Hall, and *Nuculana attenuata* Meek. In the Pawnee limestone *Lophophyllum westii* Beede, *Fenestella limbata* Foerste, *Fustulipora nodulifera* Meek, and *Hustedia mormoni* (Marc.) first assume prominence among their associates. Nineteen other species, which are among the best-known Coal Measures fossils, were introduced during Stage B. They are: *Campophyllum torquium* Owen, *Polypora elliptica* Rog., *Rhombocladia delicata* Rog., *Rhombopora lepidodendroidea* Meek, *Stenopora carbonaria* (Worth.), *Streblotrypa prisca* G. and H., *Chonetes verneuilanus* N. and P., *Dielasma bovidens* (Mort.), *Meekella striaticostata* (McChes.), *Productus costatus* Sow., *Aviculopecten carboniferus* Stev., *A. occidentalis* Shum., *Euchondria neglecta* (Gein.), *Schizodus wheeleri* Meek, *Bellerophon crassus* M. and

W., *B. percarinatus* Conr., *Euomphalus catilloides* (Conr.), *Phillipsia major* Shum., and *Tainoceras occidentale* (Swall.), together with many others.

SERIES II.

Series II consists of three stages. Stage C is made up of the Bethany Falls, Mound Valley and Dennis limestones with the intervening shales and the Cherryvale shales. Stage D is composed of the Drum limestone only. Stage E comprises the Chanute shales and the Iola limestone. These rocks are all exposed at Kansas City. Were it not for the interpolation of the Drum limestone with its striking fauna all the strata could be grouped in a single grand division.

The strong characteristics of this series are certain species first appearing in Stage I, but not continuing above the Iola limestone, and the fact that up to the present time three species of fossils usually regarded as typical of the Upper Coal Measures have not been found below the Allen limestone. They are *Chonetes granulifer* Owen,* *Entleltes hemiplicata* Hall, and the species of the genus *Fusulina*. Specimens of a species belonging to the last genus may be found in the Chanute shales at Kansas City, but they do not become of importance until much higher horizons are reached. Such species as *Lima krotowi* Stuck., *Cleiothyris orbicularis* (McChes.), *Cryptacanthia compacta* W. and St. J., *Michelinia eugeneæ* White, *Fenestella wortheni* Ulr. and *Conocardium parrishi* Worth. are unknown above the Iola limestone. To avoid repetition the other salient features peculiar to the various stages and formations will be found in the detailed discussion below.

Stage C.—This stage was inaugurated by the influx of new faunal elements into the Kansas basin. Perhaps it should be called rather two than one, as fourteen such species appear in the Bethany Falls limestone at its base and seventeen in the Dennis limestone near its top. Among these species are *Pinnatopora trilineata* (Meek), *Aulopora? prosseri* Beede, *Proboscidella* sp., *Limopteria longispina* (Cox), *Pteria longa* (Gein.), *Myalina perattenuata* M. and H., *Aviculopecten maccoyi* M. and H., *Orbiculoidea convexa* (Shum.), *Pinna peracuta* Shum., *Macrodon sangamonensis* Worth., *Domatoceras lasallense* (M. and W.), *Myalina ampla* M. and H., *Sedgwickia granosum* (Shum.), *S. topekaensis* (Shum.), *Solenomya trapezoidea* Cox,

* An occasional specimen of this species may be found in this series, but we have seen no unquestionable specimens of it.

Chænomya leavenworthensis M. and H., *Lima retifera* Shum. and *Stenopora biserialis* (Swall.). Thirteen species are found in large numbers for the first time in this stage. They are, with their horizons, as follows: Bethany Falls limestone—*Dielasma bovidens* Mort., *Chonetes verneuilanus* N. and P.; Mound Valley limestone—*Myalina subquadrata* Shum., *Spiriferina kentuckiensis* (Shum.), *Polypora elliptica* Rog., *Stenopora carbonaria* (Worth.); Galesburg shales—*Cypridella* sp.; Dennis limestone—*Aviculopecten carboniferus* Stev., *A. occidentalis* (Shum.), *Bellerophon crassus* M. and W., *Productus costatus* Sow., *Proboscidella* sp., *Rhombopora* sp. The four species which reach numerical importance only in Stage C are *Cystodictya inequimarginata* Rog., *Rhombocladia delicata* Rog., *Schizodus wheeleri* Swall., and *Bellerophon percarinatus* Conr.

Lophophyllum westii Beede culminates in the Bethany Falls limestone and *Proboscidella* sp. in the Dennis. *Euphemus nodocarinatus* (Hall), *Asymtoceras capax* (M. and W.) and *Coloceras globatum* (M. and W.) ? have been found only in rocks of this stage, and the following species have not been found in the succeeding strata; *Ephippoceras divisum* (W. and St. J.), *Pleurotomaria broadheadi* White, *Nautilus planorbiformis* M. and W. and *Pugnax rockymontana* (Marc.)

Stage D.—This is the most strongly marked of any stage in the Kansas Coal Measures. It was characterized by the invasion of an oölitic fauna so different in its general make-up that it forms a distinct and important chapter in the Coal Measures history of the state. Here we have the first strong *Pseudomonotis* fauna introduced in abundance among species supposedly incongruous with it. The fauna, like that of other oölitic faunas of this country, is strongly molluscan. The relation of the number of species of the *Mollusca* to the *Molluscoidea* is practically three to one. Many of the species introduced disappeared at the close of the stage, never to return. Some of the stronger ones reappear in the Kickapoo limestone and the *Pseudomonoti* form strong features of the Permian fauna.

One of the striking features of this fauna is, according to Doctor Bennett's list, the recurrence here of a Mississippian oölitic fauna in part. Contrasting with this we have nearly all of the known Paleozoic species of *Pseudomonotis* found in America occurring here in fair abundance. Over 400 specimens of them from this limestone have been studied by one of

the authors. This is the more remarkable when it is remembered that the species of this genus are ordinarily confined to the Permian in most foreign countries. This is in keeping, however, with much other evidence of the youth of the American Pennsylvania fauna compared to the English and European in general, indicating the proximity of the Kansas region to the point of origin of some of the higher faunas.

Seventeen or more species are peculiar to the Drum limestone. The following species are found in large numbers for the first time: *Septopora biserialis* (Swall.), *Productus nebraskensis* Owen, *Cypricardinia carbonaria* Meek, *Myalina swallowi* McChes., *Pseudomonotis hawni* var., *P. equistriata* Beede, *P. kansasensis* Beede, *Patellostium bellum* (Keyes), *Bucanopsis marcouiana* (Gein.) and *Pseudomonotis robusta* Beede. An interesting feature is the repetition of the second, fourth and fifth species in about a similar role in the Kickapoo limestone, and again together with the first in the Neosho formation.

Stage E.—Stage E includes the Chanute shales and their limestone lenses and the Iola limestone. At Kansas City the term Chanute formation would be more appropriate than Chanute shales. The entire section of this stage is shown in the bluffs at the Union Station at Kansas City. Several species of considerable range are added during this stage: *Syringopora multattenuata* McChes., *Ceriocrinus missouriensis* M. and G., *Aviculopinna americana* Meek, *Ceriocrinus craigii* Worth., *Pinnatopora pyriformopora* Rog., *Streblotrypa striatopora* Rog., *Echinocrinus triserratus* Meek, *Aulacorhynchus millepunctatus* M. and W. and *Rhabdomeson americanum* Rog. are among the best known.

Many species are peculiar to the rocks of this stage largely on account of the occurrence at Kansas City of what may be taken as the typical crinoid fauna of the time in the Chanute shale, together with a lot of vertebrates from the same formation. The crinoid fauna is of peculiar interest in comparing it with that of the Howard limestone (shale between the two layers and near them) at Topeka. Aside from the crinoids and vertebrates there are three species of *Bryozoa* and three of *Cyclus* peculiar to the stage. One of the important features of the stage is the last appearance in the Iola limestone of several of the familiar species of the rocks below. They are *Cleiothyris orbicularis* (McChes.), *Cryp-*

tacanthia compacta W. and St. J., *Strophalosia spondyliformis* W. and St. J., *Michelinia eugeneæ* White, *Fenestella wortheni* Ulr., *Conocardium parrishi* Worth., *Cyclus packardi* Rog., *Lima krotowi* Stuck.? and *Cypridella* sp. Three species, *Aviculopecten rectilaterarius* Cox, *Yoldia knoxensis* McChes. and *Ephippoceras divisum* (W. and St. J.), are unknown above the Chanute shales.

Spiriferina kentuckiensis (Shum.) culminates in the Iola limestone. *Cleiothyris orbicularis* (McChes.), *Cryptacanthia compacta* W. and St. J. (at Chanute), *Chainodictyon laxum* Foerste, *Fenestella remota* Foerste and *Cyclus communis* Rog. reach numerical importance only in the Iola limestone, while the same is true for the following species in the Chanute shales: *Campophyllum torquium* Owen, *Conularia crustula* White, *Schizodus harii* Miller, and three species of crinoids. The following species first form important elements of the fauna in the Chanute shales: *Rhipidomella pecosi* (Marc.), *Rhombopora lepidodendroidea* Meek, *Phialocrinus magnificus* (M. and G.), *Erisocrinus typus* M. and W., and *Ceriocrinus hemisphericus* (Shum.), while the same is true for *Meekella striaticostata* (Cox) in the Iola.

SERIES III.

In Series III occurs a fourth faunal incursion, the fossils of which color all the remaining faunules of the Coal Measures of Kansas.

This series is composed of three stages, F, G and H, which comprise a large part of the Kansas Coal Measures. As here defined it extends from the top of the Iola limestone to the top of the Americus limestone.

The most important elements of the fauna introduced or especially developed are *Chonetes granulifer* Owen,[275] species of *Fusulia,* and *Enteletes hemiplicata* Hall. *Fusulina* may have been introduced earlier in the northern part of the section, but attained no prominence until the Oread limestone is reached, when it swarmed the clearer seas until the close of the time represented by the top of the Cottonwood limestone and Florena shales. A few stragglers remained until well into the Permian.

The top of the Americus limestone is chosen as the top of this series on account of the thinning of the ranks of the Coal Measures species, and especially the introduction of dis-

275. *Ante.*

tinctly Permian types of fossils in the Elmdale formation of Stage I which foreshadow the typical Permian fauna. Doctor Girty finds *Bakewellia parva* M. and H. from even the Willard shales of Stage H.

Stage F.—The Lane shales, Allen limestone, Vilas shales, Stanton limestone, Le Roy shales (including Elgin sandstone), Kickapoo limestone, Lawrence shales and Oread limestone make up Stage F.

This stage is characterized by the introduction, or special development, of some very important faunal elements, *Chonetes granulifer* Owen and *Enteletes hemiplicata* Hall and *Fusulina* spp., and the exit of nearly thirty species of the older faunules. Barriers were removed which allowed these species to enter, and, once admitted, they remained until they, the last of their kind, finally left the stage of existence. A species of *Amblysiphonella* is found in the Lane shales, near the top of the Iola limestone, at Iola and becomes very abundant in the Allen limestone, as does a large species of sponge and a smaller one. The *Amblysiphonella* is found for the last time in the Oread limestone at Burlington. *Enteletes hemiplicata* Hall appears in the Allen limestone near Kansas City and is extremely abundant in the Stanton limestone at Eudora. *Pinnatopora trilineata* (Meek) becomes numerically important only in the Allen limestone, while *P. multipora* Rog. is not known above it. *Chonetes granulifer* Owen is added in the Allen limestone, and Doctor Girty records the last appearance of *Chætetes milleporaceous* M.-E. and H. from it.

The Kickapoo limestone records the imperfect reëstablishment of oölitic conditions in the northern part of the Kansas sea. The *Pseudomonotis* fauna is again present and, in general, the molluscan tendencies of the older oölitic faunule reappear, but only weakly, and the faunal assemblage as a whole is not present. *Limopteria marian* White, and *Fenestella shumardi* Prout? make their first appearance in this formation, while ten species (all pelecypods but one) are peculiar to it. Seven or eight species are found here for the last time. They include the last of the *Merostomata*, except *Prestwichia danæ* (M. and W.), which disappears in the Lawrence shales above. *Limopteria marian* White, *Edmondia nebraskensis* (Gein.), *Limopteria longispina* (Cox), *Pteria longa* (Gein.), *P. sulcata* (Gein.) and *Schizodus compressus* Rog. form important parts of no other faunule.

Thus in this horizon there is seen the beginning of a tendency to eliminate some of the older species of the fauna which culminates in the Oread limestone, where twenty species have been found for the last time. Among those disappearing with the Oread limestone are such important forms as *Cypridella americana* Rog., *Rhombocladia delicata* Rog., *Proboscidella* sp., *Amblysiphonella* sp., *Limopteria longispina* (Cox), *Aulopora? prosseri* Beede, *Euconospira missouriensis* (Swall.), *Ephippoceras ferratus* (Cox), *Domatoceras lasallense* (M. and W.), *Fenestella perelegans* Rog., *Ceriocrinus missouriensis* M. and G., *Thamniscus tenuiramus* Rog.? and *Fenestella kansasensis* Rog. *Productus cora* becomes quite as abundant here as at any other horizon.

Seven species seem to be peculiar to the Oread limestone: *Orthonema salteri* M. and W., *Pinnatopora ptiloporoidea* Rog., *Polypora missouriensis* Rog.?, *Chænocardia ovata* M. and W., *Orthoceras munstrianum* M. and W., *Derbya broadheadi* H. and C., and *Polypora spinulifera* Ulr.?

In the lower Oread there is an abundance of a slender species of *Fusulina* resembling in outward appearance *Fusulina longissima* Moell. While some important species are introduced in the Oread and Kickapoo limestones, yet the salient feature of the two horizons is the disappearance of twenty species in the former and seven or eight in the latter. After the close of Stage F this loss of species is considerably checked until the Howard limestone is reached.

Stage G.—This stage corresponds with Haworth's Shawnee formation, except that its top is placed at the top of the Howard limestone instead of the Burlingame limestone, throwing the Scranton shales into the following stage. It comprises the Kanwaka shales, Lecompton limestone, Tecumseh shales, Deer Creek limestone, Calhoun shales, Topeka limestone, Severy shales and the Howard limestone. About fifteen species are added during this stage and thirty-eight are recorded for the last time, twenty-eight of which appear last in the Howard limestone. Twenty-five species are known only from this stage. The most important introduction is that of *Strophalosia* sp. in comparative abundance in the Topeka limestone. This species is an important element of the fauna of the Florena and Garrison formations, to be noted later.

In the Lecompton limestone *Fusulina secalica* (Say) first became extremely abundant. *Fenestella hexagonalis* Rog. and

Derbya multistriata (Meek) (=*D. cymbula*) are found for the first time, while *Conularia crustula* White?, *Polypora nodocarinata* Ulr., *Septopora pinnata* Ulr. and *Trachydomia wheeleri* (Swall.) are found for the last time in the Deer Creek limestone. The appearance of *Strophalosia* and *Aclisina swallowana* (Gein.) for the first time, and the final appearance of *Phillipsia major* Shum., *Polypora submarginata* Meek, *Syringopora multattenuata* McChes., *Echinocrinus aculeata* Shum., and *Fenestella hexagonalis* Rog., are the more notable characters of the Topeka limestone faunule. *Amblysiphonella prosseri* Clarke and *Fistulipora carbonaria* Ulr. are among the more important of the seven species peculiar to it.

With the muddying of the waters of the Howardian time many of the characteristic species of the Kansas basin were smothered out, twenty-eight in all. Among them were such familiar forms as *Squamularia perplexa* (McChes.) (shown in chart as stopping at the Severy shale), *Productus pertenuis* Meek, *P. costatus* Sow., *Aviculopecten carboniferus* Stev., *Campophyllum torquium* Owen, *Chainodictyon laxum* Foerste, *Nautilus planovolvis* Shum., *Naticopsis ventricosa* McChes., *Capulus parvus* Swall., *Worthenia tabulata* Conr., *Lima retifera* Shum., *Limopteria gibbosa* (M. and W.), *Ceriocrinus craigii* Worth., *Pinnatopora pyriformipora* Rog., *Fenestella shumardi* Prout, *Polypora aspera* Rog., and *Fenestella dentata* Rog. The culmination of *Streblotrypa prisca* Gabb and Horn was also an important feature. *Yoldia subscitula* M. and W., *Bulimorpha nitidula* (M. and W.), *Allorisma geinitzi* Meek and *Sphærodoma medialis* (M. and W.) appear first in this limestone.

The crinoid fauna is also interesting, since many of the genera found in the Chanute shales are absent and species of *Ceriocrinus* and *Erisocrinus* play the leading role. It should be remarked here that most of the crinoids are found in the blue clay shale between the two layers and near them. So far as we can see the conditions were fairly similar in the two localities and the faunas may be taken as being as nearly representative as we are apt to find. The fauna here is largely that of the later Coal Measures, while the Kansas City crinoids represent an earlier type. Among the twelve species of fossils peculiar to this limestone may be mentioned *Gastrioceras subcavum* (M. and G.), *Solenocheilus collectus* M. and W.?,

Stearoceras gibbosum Hyatt and *Placunopsis carbonaria* Meek.

Stage H.—Stage H as here understood differs from the Wabaunsee formation in including, as its author did originally, the Scranton shales as its basal member. The Elmdale formation, Neva limestone and Eskridge shales are removed from the top and put in another stage. These studies have brought to light the reasons, discussed later, for making this change. It comprises the Scranton shale, Burlingame limestone, Willard shale, Emporia limestone, Admire shale and Americus limestone. *Sedgwickia altirostrata* M. and H. is first added in the Burlingame limestone. *Productus punctatus* Mart., *Myalina subquadrata* Shum., *Bellerophon percarinatus* Conr., *Bucanopsis marcouianus* (Gein.), *Myalina ampla* Meek, *Pseudomonotis robusta* Beede and *Edmondia aspenwallensis* Meek are last recorded from this horizon. *Edmondia aspenwallensis* Meek and *Allorisma terminale* Hall culminate here, so far as the strata covered in this paper are concerned. The latter is especially abundant in the Wreford limestone at Blue Springs, Neb. Seven species are peculiar to this horizon. In the Emporia limestone two cephalopods, *Gastrioceras* sp. and *Aganides* sp., form important elements in the fauna and are now known from no other horizon. *Lophophyllum westii* Beede is doubtfully recognized here for the last time. *Pleurotomaria perhumerosa* Meek is locally abundant in the region of the type locality of the Emporia limestone, and has been seen in no higher horizon. The latter statement is true of *Strophostylus nanus* (M. and W.) and *Naticopsis altonensis* McChes.

Two important genera are added in the Americus limestone, *Bairdia* and *Beyrichiella*, each represented by a single species, while *Hustedia mormoni* (Marc.) is very abundant. *Chonetes verneuilanus* N. and P. and *Allorisma Geinitzi* Meek are recorded here by Doctor Girty. It is their last occurrence in the Kansas section. *Meekopora prosseri* Ulr. becomes abundant in this limestone.

SERIES IV.

Series IV is characterized by the introduction of typical Permian species, such as *Pleurophorus whitei* Beede, *Myalina aviculoides* Meek? and *Aviculopinna nebraskensis* Beede, in the Elmdale (?). It is also significant in this connection that Doctor Girty finds *Bakewellia parva* M. and H. in the

ina robusta (Stev.)?. About twenty-five species seem to be found here for the last time, among which are such species *Dielasma bovidens* Mort., *Stenopora carbonaria* (Worth.), *Rhipidomella pecosi* (Marc.), *Pugnax utah* (Marc.), *Bairdia beedia* U. and B., *Modiola subelliptica* Meek, etc. *Productus nebraskensis* Owen and *Thamniscus octonarius* Ulr. culminate here and are found in very great numbers, especially in the southern region. *Pleurophorus subcostatus* M. and W., *Myalina kansasensis* Shum., *Derbya multistriata* (Meek) and *Schizodus* sp. are of numerical importance here for the first time.

The characteristics of this stage are the abundance of ostracods and *Strophalosia* sp., the culmination of *Productus nebraskensis* Owen and *Thamniscus octonarius* Ulr., the abundance of *Derbya multistriata* in the upper part of the section in the southern region, and the other species mentioned above. It is in the Neosho that the so-called Permian vertebrates occur, in a layer of blue clay about fifty or sixty feet below the top of the formation. These species are given at the end of the systematic list.

In some instances the occurrence of the fossils given in this discussion is known to be too limited, but it is deemed better to give and discuss the data as we have it and omit the rest rather than to include hypothetical data with the known.

Aside from the data given in discussing the faunal divisions above there are other features not discussed, such, for instance, as the horizons at which the dominating species are reduced to the ranks of the moderately common to rare species. This is an important class of evidence tending to the same results as that given, and can readily be noted on the chart.

Range of Species.

The great stratigraphic range of the species of the Kansas Coal Measures fossils has frequently excited comment. The reason for this is that the brachiopods, the best-preserved and most abundant fossils of these rocks, are conspicuous and form the great bulk of superficial collections and a large part of any collections. Certain of them are very conspicuous and are found throughout nearly the whole succession of the rocks. Before the stratigraphy had been accurately worked out and collections carefully labeled as to locality and horizon it is little wonder that those who had to deal with the subject were in-

their range, the Hooser material loses much of its diagnostic value as a horizon marker. It is of great value, however, for purposes of foreign correlation, which Mr. Spandel has very carefully discussed.[276] With further studies of this sort much light will be thrown on the complex relationships of the fauna.

Stage J.—Stage J includes the Cottonwood limestone, Florena shales and the Neosho formation. There is some question about referring the Cottonwood limestone to this stage. The faunal changes between the Eskridge and the Florena shales may have taken place prior to the deposition of this stone. In the southern part of the region it seems to be quite as closely related to the younger as to the older formations, and for that reason is here included in Stage J (or Council Grove Stage). The principal faunal element here is an abundance of *Fusulinæ*. In the northern part of the state they are never abundant after the Cottonwood limestone is passed, but farther south they become rather numerous in the Florena shales. Only a very few specimens have been seen from the Neosho formation, though they make up the bulk of the upper layer of the Cottonwood limestone.

During the deposition of the Florena shales the sea swarmed with Ostracoda, especially *Bairdia beedei* Ulrich and Bassler, and its variety *abrupta* U. and B. *Beyrichia? emaciata?* U. and B., *Beyrichia radiata* U. and B., *Beyrichiella bolliformis* U. and B., *Kirbya pinguis* U. and B., *Beyrichia haworthi* U. and B. and *Kirbya centronata* U. and B. also occur in this formation, though forming a more inconspicuous part of the faunule. The last two species are peculiar to it. *Productus semireticulatus* Mort. and *Bairdia* seem to culminate in this formation, while *Crania modesta* W. and St. J. reaches numerical importance only in it.

The main character of the Florena shale is the abundance and obesity of its brachiopod fauna. This is especially true of *Chonetes granulifer* Owen, *Seminula argentea* (Shep.) and *Productus semireticulatus* Mort. Along with these are numerous specimens of *Derbya, Meekella striatocostata* (Cox), and *Thamniscus octonarius* Ulr.

Six species are peculiar to the Neosho formation; a paleacyclid coral, a peculiar small *Ceriocrinus?*, an ophiuroid, *Chænomya maria* Worth.?, *Nucula beyrichi* V. Schaur.?, and *Aclis-*

276. Sonderabzug aus den Abhandlungen der Naturhistorischen Gesellschaft in Nuernberg, 1901. "Die Foraminiferen des Permo-Carbon von Hooser, Kansas, Nord-Amerika."

to exist, and those which occur only intermittently ... the section. In the first case the species are those ...re usually abundant and hardy and the first to migrate ... region where favorable conditions are newly established ... last ones forced out of it by the introduction of untoward conditions. In the second place there are fossils like *Streblotrypa prisca* Gabb and Horn, *Allorisma costatum* and *A. terminale* Hall, which occur only at rare intervals. Such species cannot be said to occur "throughout" a series of rocks without implying a serious error. There are, in such cases, large grou... ...n which they may not be found. The study of their occ... ...ce in such cases may lead to the discovery of the wedging ou... ...f strata, or of unsuspected overlap, or even unconformity, wh... ...h would otherwise go unnoticed. The occurrence of *Rhy...* *...otrema dentata* in the Indiana Ordivician is a case in point.[279] They are of special significance, when thoroughly worked out, in indicating the nature and extent of communication of former water bodies and the more accurate geologic history of the region.

So far as the present paper is concerned these species occurring at intervals are of no especial interest, as no deductions may be drawn from them, but when similar studies have been completed in the surrounding regions they may have considerable significance.

There are some 36 species found in the Cherokee shales or in the Fort Scott limestone and in the uppermost horizons of the Kansas Coal Measures. They are distributed as follows: *Anthozoa*, 1; *Vermes*, 1; *Bryozoa*, 5; *Brachiopoda*, 13; *Pelecypoda*, 9; *Gastropoda*, 4; *Cephalopoda*, 2; *Trilobita*, 1. Out of about 400 species some 36 species range nearly through the series and 25 completely so. That is, about a sixteenth of the species are of the widest ranged types. There are somewhere in the neighborhood of 50 new species to be added, and several known species of which we have no definite horizon. Thus, taking the whole fauna, the species of greatest range probably constitute five or six per cent. of the whole fauna. However, this fails to express the whole truth in the matter, because many species, such as *Spirifer cameratus* Mort., *Spiriferina kentuckiensis* (Shum.), *Squamularia perplexa* (McChes.), *Aviculopecten carboniferous* (Stev.), *Lima retifera* Shum., and many others with large but definitely restricted range, de-

279. Cumings, 32d Ann. Rep. Ind. Dept. Geol. Nat. Res., 1908. In press.

serve consideration. The ranges of these latter species are discussed elsewhere. The extensive range of the species of the Kansas Coal Measures may be considered as one of their chief characteristics.

The only coral with very great range is *Lophophyllum profundum* M.-E. and H. It has been found in next to the lowest and topmost horizons, and extends into the Permian in Oklahoma. With the exception of Stages C and H it may be regarded as of continuous occurrence. *Campophyllum torquium* Owen and *Aulopora? anna* Beede are two species of intermittent occurrence.

Serpula insita White tubes are found in occasional horizons above the Cherokee shales to the top.

Fenestella limbata Foerste ranges from Stage B to the top of the section, as do *Rhombopora lepidodendroidea* Meek, *Stenopora carbonaria* (Worth.) and *Streblotrypa prisca* Gab and Horn. Except the second they are rather intermittent in their occurrence. *Fistulipora nodulifera* Meek is the only bryozoan extending fairly continuously throughout the succession of rocks.

Ten species of *Brachiopoda* range through the series, most of them without serious interruption. They are *Ambocœlia planoconvexa* (Shum.), *Crania modesta* W. and St. J., *Derbya crassa* M. and H., *Orbiculoidea missouriensis* (Shum.), *Productus cora* d'Orb. (probably not in the strict sense), *P. nebraskensis* Owen, *P. semireticulatus* Mart., *Pugnax utah* (Marc.), *Rhipidomella pecosi* (Marc.) and *Seminula argentia* (Shep.) The three following species are wanting in the Cherokee shales but have the same range above them: *Derbya keokuk* Hall, *Dielasma bovidens* Mort. and *Meekella striaticostata* (McChes.) With the exception of the first one these three species are found nearly continuously throughout the section. In some instances the charts do not record these species from the uppermost horizons, but they are known to occur in the Permian rocks above.

Among the pelecypods, *Allorisma costatum* M. and W., *A. terminale* Hall, *Entolium aviculatum* (Swall.) (?), *Nucula ventricosa* Hall and *Nuculana attentuata* Meek are found in the lowest and highest formations, the second rather constantly, and the others rather intermittently. *Aviculopecten occidentalis* (Shum.), *Edmondia aspenwallensis* Meek (?), *Euchondria neg-*

lecta (Gein.) and *Schizodus wheeleri* Swall. occur occasionally, at least, except in the Cherokee shales.

Euphemus carbonarius (Cox) is found fairly continuously, for a gastropod, throughout the series, while *Bellerophon crassus* M. and W., *Euomphalus catilloides* (Conr.) and *Patellostium montfortianum* (N. and P.) occur occasionally throughout the section above the basal member, *Euomphalus catilloides* (Conr.) being the most prominent and the most continuous in its occurrence.

None of the cephalopods are found both in the uppermost and lowermost horizons. Those approximating it most closely are *"Orthoceras" rushense* McChes. and *Tainoceras occidentale* (Swall.), occurring at intervals above Stage A.

Griffithides scitula M. and W. is the only trilobite that ranges nearly through the whole section. It has not yet been found in the Cherokee shales nor in Stage H.

We cannot drop this discussion without recalling an idea differently stated in another chapter. If the species given in these lists were divided as they are by some paleontologists, the range of several of them would be considerably restricted and the number of species considerably increased. In these lists the specific lines are rather loosely drawn in some instances. This is particularly true of some of the species of *Productus*. But there are other species which hardly fall in this class. Some paleontologists describe species closely and without any reference to the life-history of the species, giving each stage a separate specific name. On the other hand, there are those who include in a species all the forms found throughout a series of sediments, with all the variations due to the life-cycle. Then there is a third class, who describe these different stages as varieties, in which case they are indistinguishable from local variations, so far as the nomenclature goes. However, they may be distinguished by varieties if certain adjectives are used, such as "geronticus," "senelis," "moritura," etc., which would designate the relationships of the varieties.

Thus *Seminula argentia* (Shep.) might be described under two, and, more probably, three species, with definite limited range, or as a single species with a very great range, or as a species and two varieties, the latter with limited vertical distribution. In the same way *Chonetes granulifer* Owen could

be represented by two or three varieties, each with restricted geologic horizon.

It will be seen that the recognition of these finer facts will tend to restrict the range of species and to accentuate the characteristics of the faunal stages.

List of Localities.

It may be well to give a list of the localities from which collections were made and specimens noted. Unfortunately this can only be done for that part of the region collected over by the writers and in a general way by Doctor Bennett. Doctor Bennett's collecting, so far as the present paper is concerned, was in the vicinity of Kansas City, Fort Scott and Pittsburg.

Doctors Adams and Girty do not give any localities from which their collections were made, which restricts the known geographic extent to which any particular horizon has been collected.

The following localities are given by horizons. This gives the point from each horizon from which our data upon which the paper is based were derived. These are all given in detail in the last three of the "Faunal Studies" published.[280]

Cherokee shales:

Shaft one mile southwest of Cherokee.
Limestone outcrop a half mile west of Cherokee.
North Leavenworth and Riverside coal-shafts, Leavenworth.
Carr coal-shaft at Richardson, Leavenworth county.
Shaft one and a half miles northeast of Frontenac.
Strip pit a mile and a half southeast of Oswego.

Fort Scott limestones:

Various exposures in the vicinity of Fort Scott.
At Oswego, railroad cut just east of the Frisco station.
Various exposures about McCune.
Cement works above Fort Scott.
Various exposures at and near Girard.

Labette shales:

Fort Scott, one mile east of the city and one and a half miles southwest of the city on the Minden branch of the Missouri Pacific railroad.
One and a half miles southwest of Laneville.

Pawnee limestone:

North of National cemetery southeast of Fort Scott.
Bridge over Marmaton river a half mile south and a mile and a half west of Marmaton station.
Northeast of Farlington station on the little creek.

280. Loc. cit.

) limestone—continued:
rd, one and a half miles northwest of town.
and a half miles southwest of Laneville.

nt limestone:
ilfillan.
of Marmaton river a mile east of Uniontown.
) miles east and a mile south of Walnut.

Bethany Falls limestone:
Exposures in and about Kansas City.
Railroad cut at Trent siding, three miles east of Erie.
Pleasant Hill, Mo. (in part).

Mound Valley limestone:
In and about Kansas City.
Wagon road on west side of) river a little south of west of Erie.
A. T. & S. F. railroad cut three west of Erie. Base of bluff.

Galesburg shales:
Kansas City and vicinity.

Dennis limestone:
Kansas City and vicinity.
Top of bluff at A. T. & S. F. railroad cut three miles west of Erie.
Bluffs of A. T. & S. F. railroad cut just west of Shaw.

Cherryvale shales:
Kansas City and vicinity.

Drum limestone:
Outcrops in the region about Kansas City.
Quarry near Turner.

Chanute shales:
Kansas City and vicinity.

Iola limestone:
Iola.
Chanute.
Kansas City and vicinity.

Lane shales:
Exposures in the Kansas City region.
Iola.

Allen limestone:
Iola.
Argentine.
Carlyle.

Stanton limestone:
Near Neosho Falls.
Eudora.

Kickapoo limestone:
Region about Lawrence.

Lawrence shales:
Seven miles southwest of Lawrence (Sellards).

Oread limestone:
Vicinity of Lawrence.
Lecompton.
Vicinity of Burlington.

Deer Creek limestone:
Throughout eastern Shawnee county.

Topeka limestone:
Throughout its exposure in Shawnee county.

Severy shales:
Coal-mines three miles southwest of Topeka.
Coal-mines two miles west of Topeka.
Coal-mines at Burlingame.

Howard limestone:
Carbondale.
Exposures within five miles of Topeka.

Scranton shales:
Junction of Mission and Blacksmith creeks west of Topeka.
Railroad cuts east of Valencia.
Brick-yard shale-pit east of old sugar-works west of Topeka.

Burlingame limestone:
Throughout its outcrop in Shawnee county.

Emporia limestone:
Emporia.
Mission creek near Dover.
Wakarusa creek near Auburn.

Americus limestone:
Americus.

Elmdale formation:
Elmdale.
East of Barrett.
Vicinity of Manhattan.
Buffalo Mound near Paxico.
Reece.
Beaumont.
Grand Summit.
South of Hooser.

Neva limestone:
West of Manhattan, Ulrich's upper quarry.
Grand Summit.
Elmdale.
Hooser.

Eskridge shales:
West of Manhattan, Ulrich's upper quarry.
Grand Summit.
Hooser, south of the station near big curve.

limestone—continued:
rd, one and a half miles northwest of town.
and a half miles southwest of Laneville.

nt limestone:
ilfillan.
of Marmaton river a mile east of Uniontown.
miles east and a mile south of Walnut.

Falls limestone:
sures in and about Kansas City.
Rail oad cut at Trent siding, three miles east of Erie.
Pleasant Hill. Mo. (in part).

Mound Valley limestone
In and about Kansas
Wagon road on west side
river a little south of west of Erie.
A. T. & S. F. railroad cut thr
west of Erie. Base of bluff.

Galesburg shales:
Kansas City and vicinity.

Dennis limestone:
Kansas City and vicinity.
Top of bluff at A. T. & S. F. railroad cut three miles west of Erie.
Bluffs of A. T. & S. F. railroad cut just west of Shaw.

Cherryvale shales:
Kansas City and vicinity.

Drum limestone:
Outcrops in the region about Kansas City.
Quarry near Turner.

Chanute shales:
Kansas City and vicinity.

Iola limestone:
Iola.
Chanute.
Kansas City and vicinity.

Lane shales:
Exposures in the Kansas City region.
Iola.

Allen limestone:
Iola.
Argentine.
Carlyle.

Stanton limestone:
Near Neosho Falls.
Eudora.

Kickapoo limestone:
Region about Lawrence.

Lawrence shales:
Seven miles southwest of Lawrence (Sellards).

Oread limestone:
Vicinity of Lawrence.
Lecompton.
Vicinity of Burlington.

Deer Creek limestone:
Throughout eastern Shawnee county.

Topeka limestone:
Throughout its exposure in Shawnee county.

Severy shales:
Coal-mines three miles southwest of Topeka.
Coal-mines two miles west of Topeka.
Coal-mines at Burlingame.

Howard limestone:
Carbondale.
Exposures within five miles of Topeka.

Scranton shales:
Junction of Mission and Blacksmith creeks west of Topeka.
Railroad cuts east of Valencia.
Brick-yard shale-pit east of old sugar-works west of Topeka.

Burlingame limestone:
Throughout its outcrop in Shawnee county.

Emporia limestone:
Emporia.
Mission creek near Dover.
Wakarusa creek near Auburn.

Americus limestone:
Americus.

Elmdale formation:
Elmdale.
East of Barrett.
Vicinity of Manhattan.
Buffalo Mound near Paxico.
Reece.
Beaumont.
Grand Summit.
South of Hooser.

Neva limestone:
West of Manhattan, Ulrich's upper quarry.
Grand Summit.
Elmdale.
Hooser.

Eskridge shales:
West of Manhattan, Ulrich's upper quarry.
Grand Summit.
Hooser, south of the station near big curve.

ood limestone:
ty, Barrett, Bigelow, Florena, Manhattan, Cottonwood Falls and
cinity, Beaumont, Grand Summit.

shales:
e as Cottonwood limestone.

formation:
Riley, Council Grove and vicinity, Reece, Beaumont, Grand Sum-
it, Dexter, Hooser.

THE CHART.

Inasmuch as the critical character of a fauna depends quite as much upon the nature of the faunal assemblage as the species present, the writers endeavored to produce a chart which would show this assemblage graphically. In order to accomplish this it was necessary to subordinate both alphabetic and zoölogic order to an order that possessed neither of these characters, with an added inconvenience of reference. For convenience of reference a separate list is published preceding the chart, with the classes or subclasses systematically arranged and the genera arranged alphabetically under them.

The formations are arranged from below upwards, reading from left to right. The horizontal spaces represent the range of the species in these horizons. The fauna of any given formation is shown by the vertical column beneath its name. Several means of designating the occurrence of a species in a horizon will be noted on the chart. In the first place, the upper part of the chart has a very different appearance from the lower part, on account of the blackened or half-blackened spaces. These spaces represent the relative abundance (percentage, roughly speaking) of the individuals of a species with those of any remaining species. To illustrate: We first took the species found in the lowest horizon (Cherokee shales) and found that *Productus muricatus* N. and P. dominated the whole faunule; that is, they were more abundant than the specimens of any other species. It was selected as the first of the list and represented on the chart with a fully blackened space. Then it was found that there were four other species whose specimens played a very important part in the faunule and were more abundant than those of the remaining species. They were put in next in half-blackened spaces.

The list from this horizon was then laid aside and that of the following horizon (Fort Scott limestone) was taken up and treated similarly. It was found that three of the species represented in the previous selections were abundant in this horizon, and they were carried over in half-blackened spaces. It was found that *Chætetes milleporaceous* M.-E. and H. in places was so abundant as to form reefs and made up most of the bulk of the stone, and it was added in a fully blackened space, and then the remaining ten species which were found to be considerably more abundant than any of the remaining species were added in half-blackened spaces. It sometimes happens that two or more species are so much more abundant than any of the rest that they have to be represented by fully blackened spaces, as in the Florena shales. After the lists of all the horizons had been treated in this way, in which 111 species had been selected out, we returned again to the lowermost horizon and added all the species which had not been represented in the 111 already used, and added them to the list. We then took up the list of the next horizon and added those species not already on the chart, and so on until the chart was complete.

The lowermost horizon in which a species has been found is indicated by a cross with the left arm removed. In the Cherokee shales they are not marked in this way, as there is no way, at present, of determining how many of them may be represented in lower Coal Measures rocks in the Arkansas or other regions. The ordinary way of representing a species when present in moderate numbers or rare is by the full cross. When a species occurs for the last time this horizon is marked by a cross with the right arm removed. In case, however, it is suspected or known to occur in the Permian rocks above it is left with the full cross. Several such instances will be noted in the chart. In case it is confined to a single hori-

SYSTEMATIC CHART.—FIRST HALF.

Species.	Series I.							Series II.														
Stage ☞	A	B						C					D	E		F						
	Cherokee sh.	Fort Scott ls.	Labette sh.	Pawnee ls.	Bandera sh.	Altamont ls.	Walnut-Pleasanton sh.	Bethany Falls ls.	Ladore sh., Mound Valley ls.	Galesburg sh.	Dennis ls.	Cherryvale sh.	Drum ls.	Ch[illegible] sh.	Iola ls.	Lane sh.	Allen ls.	Vilas sh., Stanton ls.	Le Roy sh.	Kickapoo ls.	Lawrence sh.	Oread ls.
FORAMINIFERA.																						
Ammodiscus concavus 376																						
Bigenerina cf. eximia 377																						
Dentalina bradyi 378																						
Fusulina sp. 88																	X	X		X		A
Fusulinella sp. 9		C		C		X		?														
Lituola ?? sp. 275																						
Monogenerina atava 379																						
Monogenerina nodosariformis 380																						
Nodosaria postcarbonica 381																						
Schwagerina sp. 382																						
Tetraxis conica 383																						
Textularia gibbosa 384																						
SPONGIÆ.																						
Amblysiphonella prosseri 322																						
Amblysiphonella sp. 68																X	A					X
Somphosphongia multiformis 359																						
Sponge sp. 69															X		A					
Sponge sp. 71																	C					C
ANTHOZOA.																						
Aulopora ? anna 163		X									X											X
Aulopora ? prosseri 73								X												C		C
Axophyllum rude 13	X	C		C		X		C						X	X							X
Campophyllum torquium 53		X		X				X						C				B				X
Chætetes milleporaceous 6	X	A		C		G												G				

Cladochonus bennetti
Coral sp. 396
Lophophyllum profundum 74
Lophophyllum westii 22
Michelinia eugenese 145
Syringopora multattenuata 254
CRINOIDEA.
Cœlocrinus craigi 280
Cœlocrinus harshbargeri 341
Cœlocrinus hemisphericus 61
Cœlocrinus missouriensis 267
Cœlocrinus monticulatus 342
Cœlocrinus nodulifera 256
Cœlocrinus? sp 396
Cromyocrinus sangamonensis 225
Cyathocrinus stillativus 226
Erisocrinus megalobrachius 343
Erisocrinus toddi 257
Erisocrinus typus 60
Eupachycrinus harii 258
Eupachycrinus magister 259
Eupachycrinus sphæralis 250
Eupachycrinus tuberculatus 204
Hydreionocrinus acanthophorus 209
Hydreionocrinus discus 277
Hydreionocrinus mucrospinus 157
Hydreionocrinus pentaxonus 227
Hydreionocrinus subsinuatus 290
Phialocrinus basilicus 261
Phialocrinus brachydactylus 262
Phialocrinus harii 283
Phialocrinus lykensi 264
Phialocrinus magnificus 59
Scaphiocrinus washburni 344
OPHIUROIDEA.
Ophiuroid 397
ECHINOIDEA.
Echinocrinus aculeatus 90
Echinocrinus edgarensis 368
Echinocrinus mesastylus 373
Echinocrinus spinoclavatus 369
Echinocrinus triserratus 283
Echinocrinus trudifer 323
Oligoporus?? minutus 319
Pholidocidaris sp. 386

SYSTEMATIC CHART — CONTINUED.

Species.	Stage	Series I.						Series II.												
		A	B					C						D	E					
		Cherokee sh.	Fort Scott ls.	Labette sh.	Pawnee ls.	Bandera sh.	Altamont ls.	Walnut-Pleasanton sh.	Bethany Falls ls.	Ladore sh., Mound Valley ls.	Galesburg sh.	Dennis ls.	Cherryvale sh.	Drur.. ..s.	C h.	Iola ls.	Lane sh.	Allen ls.	Vilas sh., Stanton ls.	Le Roy sh.	Kickapoo ls.	Lawrence sh.	Oread ls.
VERMES.																							
Serpulpa insista 96.			X													X		X					
Spirorbis carbonaria 196.																X							
BRYOZOA.																							
Acanthocladia pinnata 228.																C							
Chainodictyon laxum 65.					X				X		X					C							
Cystodictya divisa 269					C						X	X				X							
Cystodictya inequimarginata 40.									X			C		X		X							
Fenestella dentata 339.																							
Fenestella hexagonalis 321.																X							
Fenestella kansasensis 247.																X							
Fenestella limbata 23.			X		C				X		X					C		X					
Fenestella mimica 330.																X							
Fenestella ovatipora 270.																X							
Fenestella perelegans 232.														X		X							
Fenestella remota 65.												X				C		X					
Fenestella shumardi 298.																							
Fenestella wortheni 146.			?													X		?					
Fistulipora carbonaria 326.																							
Fistulipora nodulifera 24.			X		C		X		X	C	X	X		C		A	X	X					
Meekopora prosseri 99.																X							
Pinnatopora multipora 192.											X	X						X					
Pinnatopora ptiloporoidea 311.																							
Pinnatopora pyraformipora 281.																							
Pinnatopora trilineata 72.									X			X				X		C	X				
Pinnatopora whitii 158.																X							
Polypora aspera 317.			X		X											X							
Polypora elliptica 31.			X		X				X	C	X	X		X		C					C		

Polypora flexuosa 278															X							?
Polypora missouriensis 312																						?
Polypora nodocarinata 236														X								
Polypora spinulifera 316																						?
Polypora submarginata 155								X						X	X							X
Polypora triangularis 75														A	X					C		C
Prismopora serrata 178		G				G																
Prismopora triangulata 10	X	C		X																		
Rhabdomeson americanum 285															X							X
Rhombocladia delicata 27		X		X		X		C			X			X	X		X					X
Rhombopora lepidodendroidea 57		X	G	X				X						C	C			X				C
Rhombopora sp. 42	X	X						X	X		C	X		C		C						
Septopora biserialis 43									X		X		C	C	X	X		X		X		X
Septopora interporata 246														X	X							
Septopora multipora 271															X							
Septopora pinnata 279															?							
Stenopora carbonaria 82		X	X	X				X	C	X	C		C	X	X							C
Stenopora ohioensis 265														X								
Stenopora spinulosa 266														X	X							
Streblotrypa prisca 91		X																				X
Streblotrypa striatopora 282															X							X
Thamniscus octonarius 107																						
Thamniscus tenuiramus 276															X							?
BRACHIOPODA.																						
Ambocoelia planoconvexa 5	C	C	C	C		C		C	X	X		A	B	X	C	X	B	B				C
Aulacorhynchus millepunctatus 284															X					X		
Chonetes variolatus 113	?	X		X		G									G		X	G				X
Chonetes geinitzi 181						G																
Chonetes granulifer 76								B										X		C		C
Chonetes mesolobus 4	C	X	A	X		X	B															
Chonetes verneuilanus 28		X						C	X	X		A		X	X	X	X			X		B
Cleiothyris orbicularis 62	X	X		X		X					X			X	C							
Crania modesta 105	X	X		X							X				X		X					X
Cryptacanthia compacta 63				X		X									C							
Derbya bennetti 77	X	X													?					C		C
Derbya broadheadi 315																						B
Derbya crassa 17	X	X	C			G		X			X			C	X		X	G				X
Derbya keokuk 78								X							?			B		C		C
Derbya multistriata 108																						
Dielasma bovidens 26		X		X		G		C	X		X		C	X	C		C	X		X		X
Enteletes hemiplicata 70																	A	A				C
Hustedia mormoni 25	X	X		C		X		X	X	C	X		C	X	C	X	X					C
Lingula carbonari 130	G																					
Lingula unbonata 92	X										X			X								
Marginifera longispina 12	X	C	C	C		C		A		C	C	C	X	C	A	X	C	X		X		C
Marginifera muricata 1	A	X	X	X							X											
Meekella pyramidalis 288																		G?				G?
Meekella striaticostata 64		X		X		G		X	?					X	C			X		C		C
Orbiculoidea convexa 188								?						X	X							

SYSTEMATIC CHART—CONTINUED.

Species.	Series I.							Series II.							Ser							
Stage	A	B						C					D	E	F							
	Cherokee sh	Fort Scott ls	Labette sh	Pawnee ls	Bandera sh	Altamont ls	Walnut-Pleasanton sh	Bethany Falls ls	Ladore sh., Mound Valley ls	Galesburg sh	Dennis ls	Cherryvale sh	Drum ls	Chanute sh	Iola ls	Lane sh	Allen ls	Vilas sh., Stanton ls	Le Roy sh	Kickapoo ls	Lawrence sh	Oread ls
BRACHIOPODA—CONCLUDED.																						
Orbiculoidea manhattanensis 370																						CX
Orbiculoidea missouriensis 18	X	X	C	B		C	B	B						X	X					C		
Proboscidella sp. 41											C							G				
Productus auriculatus 137		?																				
Productus cora 19	X	X	C	X				X	X	C	X		B	C	C	C	C	G		C		A
Productus costatus 39		X		X				X	X	C	X		X	C		X	B	B				X
Productus nebraskensis 44	X		X			G		X	X		C		C	X	C		X	X		C		X
Productus pertenuis 14		C		X		G		X	X	A	C			X	C			X		A		X
Productus punctatus 8		C				G		X	X		C			X	X					C		
Productus semirecticulatus 7	X			X		X		X	X	X	B		X	X	X	X		X		X		X
Productus symmetricus 242											B		B	X								
Pugnax rockymontana 179						G		B														
Pugnax utah 79	X	X				X		X			G			X	X	X	X			C		
Rhipidomella pecosi 54	X	X	X	X				X	X	X				C	A		A	X				
Seminula argentea 3	C	C	C	C		C		C	A	C	A	C	C	C	C	C	A	X		C		
Seminula subquadrata 173				?																		
Spirifer cameratus 11	X	CX		X		X		CX	CX	X	CX		CC	C	X	X	C	X		X		CC
Spiriferina kentuckiensis 30	XC	C		A		A		X	X	C	C		C	X	C	X	G			X		C
Squamularia perplexa 2	C																					
Strophalosia sp. 89		X		X					X						X							
Strophalosia spendyliformis 144																						
PELECYPODA.																						
Allorisma costatum 116	X												X		X							B
Allorisma geinitzi 356																						
Allorisma? kansasensis 345																						
Allorisma terminale 94	X	X						B			X		B		X		B					X

Astartella gurleyi 335																						
Astartella varica 117	?																					
Astartella vera 177						G							B									
Aviculopecten carboniferus 34		X		X				X	X	X	C		X	X	C		C			X		X
Aviculopecten coxanus 237													B									X
Aviculopecten germanus? 297																				?		?
Aviculopecten hertzeri 200											X											
Aviculopecten interlineatus 114	X	X		X						X			B	X	X		B					
Aviculopecten maccoyi 186								X					X		X					X		X
Aviculopecten occidentalis 35		G									C		C	C	X	X	X	X		C		X
Aviculopecten providencensis 151		X									X		X									X
Aviculopecten rectilaterarius 115	X		X											X								
Aviculopecten? sculptilis 255													X	X						X		
Aviculopecten whitei 340																						
Aviculopinna americana 268														X								
Aviculopinna illinoiensis 183								X						X								
Aviculopinna nebraskensis 374																						
Cardiomorpha missouriensis 331													X									
Chænocardia ovata 313																						B
Chænomya cooperi 243																						?
Chænomya leavenworthana 205											?									X		B
Chænomya maria 398																						
Clinopistha radiata 170				?																		
Clinopistha radiata lævis 336																						
Conocardium acadianum 138		X																				
Conocardium obliquum 241													B									
Conocardium parrishi 147		X		X				X			X				?							
Crenipecten winchelli 210													B									
Cypricardinia carbonaria 45													C		?					X		
Edmondia aspenwallensis 95		?									X											
Edmondia nebraskensis 80													X	X						C		B
Edmondia ovata 360																						
Edmondia reflexa 185								G?														
Entolium aviculatum 118	?								X		X				X			X		?		
Euchondria neglecta 166		G																				
Leda arata 327																						
Lima retifera 190									X		X		X	X	X					X		X
Lima krotowi 149		X							X						X							
Limopteria alata 230													X							X		
Limopteria gibbosa 239													X	X						X		
Limopteria longispina 81								X			X		X							C		X
Limopteria marian 82													X							C		X
Limopteria subalata 295																				X		
Macrodon carbonarius 365													B									
Macrodon obsoletus 244													X	X						X		
Macrodon sangamonensis 197											?				?					X		
Macrodon tenuistriatus 129	X	?											B									
Microdon oblonga 211													B									
Modiola? subelliptica 245													X	X						X		
Myalina ampla 203											X											

SYSTEMATIC CHART—CONTINUED.

Species.	Series I.							Series II.														
Stage ☞	A	B						C					D	E		F						
	Cherokee sh.	Fort Scott ls.	Labette sh.	Pawnee ls.	Bandera sh.	Altamont ls.	Walnut-Pleasanton sh.	Bethany Falls ls.	Ladore sh., Mound Valley, ls.	Galesburg sh.	Dennis ls.	Cherryvale ls.	Drum ls.	Chanute sh.	Iola ls.	Lane sh.	Allen ls.	Vilas sh., Stanton ls.	Le Roy sh.	Kickapoo ls.	Lawrence, sh.	Oread ls.
PELECYPODA—CONCLUDED.																						
Myalina aviculoides 372																						
Myalina congeneris? 358																						
Myalina? exasperata 332																						
Myalina kansasensis 109													X	X	X							G
Myalina perattenuata 101								G			G											
Myalina permiana 102																						
Myalina recurvirostris 233																						B
Myalina subquadrata 29		X							C				X	X	X	C				C		
Myalina swallowi 46			X	X					X				C	C				G		C		X
Myalina wyomingensis 318																						
Nucula beyrichi 399																						
Nucula parva 212													B									
Nucula pulchella 291																				X		
Nucula sp. 385																						
Nucula ventricosa 20	X	B	C			G					X		C									X
Nuculana attenuata 21	X		C										C									
Nuculana bellistriata 159		B											B	X			X			X		X
Pinna lata 346																						
Pinna peracuta 189								B	G		G		B									X
Pinna subspatulata 320																						
Placunopsis carbonaria 347																						
Pleurophorus angulatus 213													B									
Pleurophorus oblongus 214													B									
Pleurophorus occidentalis 364													B									
Pleurophorus subcostatus 110													X							?		
Pleurophorus tropidopherus 202											X		X									
Pleurophorus whitei 375																						
Posidonomya? pertenuis 292																				X		

Posidonomya? recurva 298																				X		
Prothyris elegans 231													B							?		
Pseudomonotis equistriata 48																		G				G
Pseudomonotis kansasensis 49									?		X		C							X		
Pseudomonotis hawni 47													C							C		
Pseudomonotis robusta 52													C									
Pteria longa 83								?	X		X		B	X						C		
Pteria sp. 387																						
Pteria sulcata 84													X		X					C		
Schizodus alpina 348																						
Schizodus cf. circularis 349																						
Schizodus compressus 85																				C		
Schizodus curtiformis 324																						
Schizodus curtus 329																						
Schizodus harei 58		?												C								
Schizodus rossicus 325																						
Schizodus sp. 111																						
Schizodus subcircularis 294																				X		
Schizodus wheeleri 36		?									C		B									X
Sedgwickia altirostrata 363																						
Sedgwickia granosum 204											X				X		B					X
Sedgewickia topekensis 206											X			X								
Solenomya parallela 198											X									X		
Solenomya radiata 191									X													
Solenomya trapezoidea 207											X											
Streblopteria tenuilineata 229													?	?								
Yoldia glabra 296																				X		
Yoldia knoxensis 127	X													?								
Yoldia subscitula 354																						
SCAPHOPODA.																						
Plagioglypta meekana 240													B	X								
GASTROPODA.																						
Aclisina minuta 125	X		X																			
Aclisina robusta 400																						
Aclisina swallowana 328																						
Anomphalus rotulus 201											X											
Bellerophon crassus 37		X				G		G			C		B?							X		C
Bellerophon percarinatus 38		B						X			C			C								
Bellerophon stevensanus 215													B									
Bucanopsis marcouiana 51													C							X		
Bucanopsis meekana 353																						
Bulimorpha chrysalis 164		?													?							
Bulimorpha inornata 126		?											B									
Bulimorpha nitidula 355													B									
Capulus parvus 174				X						X				X	X	X	B					
Dawsonella meeki 371																						
Euconospira missouriensis 152		B		X				X			X			X	X		X			X		B

SYSTEMATIC CHART—CONTINUED.

Species.	Series I.							Series II.								Series						
Stage ☞	A	B						C					D	E		F						
	Cherokee sh.	Fort Scott ls.	Labette sh.	Pawnee ls.	Bandera sh.	Altamont ls.	Walnut-Pleasanton sh.	Bethany Falls ls.	Ladore sh., Mound Valley ls.	Galesburg sh.	Dennis ls.	Cherryvale sh.	Drum ls.	Chanute sh.	Iola ls.	Lane sh.	Allen ls.	Vilas sh., Stanton ls.	Le Roy sh.	Kickapoo ls.	Lawrence sh.	Oread ls.
GASTROPODA—CONCLUDED.																						
Euomphalus catilloides 165		?				G		X			X			X								G
Euphemus carbonarius 133	?	B		X		G		X					B	X						X		B
Euphemus nodocarinatus 182								G														
Loxonema rugosum 142		B?											B									
Murchisonia nebraskensis 103																						
Naticopsis altonensis 162		B																		X		
Naticopsis monilifera 216													B									
Naticopsis ventricosa 161		B		B									B									
Orthonema salteri 310																						X
Orthonema subtæniatum 333																						
Patellostium bellum 50		?											C							?		
Patellostium mortfortianum 134	X	B																				
Patellostium textiliforme 221													B									
Phanerotrema grayvillensis 180						G							B		G							
Platyceras nebraskensis 287																	G					
Pleurotomaria bonharborensis 234													B									B
Pleurotomaria brazoensis 131	X																					
Pleurotomaria broadheadi 141		B									X											
Pleurotomaria carbonaria 112	X																					
Pleurotomaria coniformis 217													B									
Pleurotomaria coxana 218													B									
Pleurotomaria inornata 219													B									
Pleurotomaria perhumerosa 96																						
Pleurotomaria scitula 119	?																					
Pleurotomaria subdecussata 93																						
Soleniscus ? anguliferus 334																						
Soleniscus paludinæformis 361																						
Sphærodoma intercalaris 135														X								

Sphærodoma medialis 357																						
Sphærodoma ponderosa 289																		G?				G
Sphærodoma toxana 362																						
Strophostylus nanus 132	?	X						X					X									
Trachydomia nodosum 220													B									
Trachydomia wheeleri 184								X					B		X							
Trepospira illinoiensis 338																						
Trepospira spherulata 128	X	B		B		G							B									?
Worthenia speciosa 143		B											B									
Worthenia tabulata 176				X		G					X											
PTEROPODA.																						
Conularia crustula 56		B											B	C								
CEPHALOPODA.																						
Asymptoceras capax 193											X											
Asymptoceras newloni 120	X																					
Aganides sp. 366																						
Coloceras cf. globatum 194											X											
Domatoceras lasallense 199											X											?
Domatoceras umbilicatum 121	X																					
Endolobus missouriense 222													B									
Ephippoceras divisum 140	X													X								
Ephippoceras ferratum 153		X						B			X		X									X
Gastrioceras subcavum 350																						
Gastrioceras sp. 97																						
Metacoceras sangamonense 187								?			X		X							X		B
Nautilus planorbiformis 169											X											
Nautilus planovolvis 160	B	X									X		X							X		
Nautilus toddi 223													B									
Orthoceras cribosum 136											X											X
Orthoceras munstrianum 314																						B
Orthoceras rushense 167		B				G					X		B									
Solenocheilus sp. 351																						
Stearoceras gibbosum 352																						
Tainoceras occidentale 168		B									X			X						X		X
Temnocheilus crassus 122	X																					
Temnocheilus depressus 123	X																					
Temnocheilus latus 124	X																					
Titanoceras ponderosum 195											X		X					B				
TRILOBITA.																						
Griffithides scitula 16		C		X					X				B		X		X			X		X
Phillipsia major 156		X						X	X		X		X	X	X	X	B		B			
Phillipsia nodocostatus 224														X								

SYSTEMATIC CHART—CONTINUED.

	Series I.							Series II.									Series III.						
Stage ☞	A	B						C					D	E		F						
Species.	Cherokee sh.	Fort Scott ls.	Labette sh.	Pawnee ls.	Bandera sh.	Altamont ls.	Walnut-Pleasanton sh.	Bethany Falls ls.	Ladore sh., Mound Valley ls.	Galesburg sh.	Dennis ls.	Cherryvale sh.	Drum ls.	Chanute sh.	Iola ls.	Lane sh.	Allen ls.	Vilas sh., Stanton ls.	Le Roy sh.	Kickapoo ls.	Lawrence sh.	Oread ls.
OSTRACODA.																						
Bairdia beedei 104																						
Bairdia beedei abrupta 106																						
Beyrichia? emaciata 391																						
Beyrichia haworthi 388																						
Beyrichia radiata 392																						
Beyrichiella bolliaformis 393																						
Beyrichiella bolliaformis tumida 367																						
Cypridella americana 15		C		X				X		X					X		X			X		
Cypridella sp. 33										C					C							
Cypridina subovata 154		X		X				X		X					X					X		
Cypridinella sp. 150		X													X							
Entomis sp. 172				X				X		X												
Kirbya centronata 389																						
Kirbya pinguis 394																						
Paraparchites humerosus 100																						
MEROSTOMATA.																						
Cyclus communis 67										X					C		X					
Cyclus limbatus 272															X							
Cyclus minutus 273															X							
Cyclus packardi 148		X						X							X							
Cyclus permarginatus 274															X							
Prestwichia danæ 235																					X	
INSECTA.*																						
Ectoblattina, Gen. et sp. nov. 86																			C			
Etoblattina coreacea 300																			X			

Etoblattina juvenalis 299																			X			
Etoblattina occidentalis 301																			X			
Etoblattina sp. 302																			X			
Gerablattina arcuata 303																			X			
Hænoblattina sp. 304																			X			
Hænoblattina sp 30?																			X			
Schizoblattina multinerva 306																			X			
Schizoblattina sp. 307																			X			
Spiloblattina maledicta 87																			C			
Spiloblattina sp. 308																			X			
Spiloblattina sp. 309																			X			
VERTEBRATA.																						
Sagenodus copeanus 337																						
Agassizodus variabilis 286																?						
Cladodus mortifer 390																						
Cruriceps parva 250														X								
Duovestigia scala 251														X								
Lystracanthus hystrix 55														C								
Notalacerta jacksonensis 252														X								
Notalacerta missouriensis 253														X								
Notamphibia major 249														X								
Peripristis semicircularis 175				X				X							X							
Petalodus ohioensis 238													B									
Petrodus occidentalis 139		B				B								X								
Punctatumvestigium circuliforme 248																						

* The data on the insects were kindly furnished by Dr. E. H. Sellards.

Second half of chart follows.

SYSTEMATIC CHART.—SECOND HALF.

Species.	Stage ☞	Series III—*Concluded.*																Series IV.					
		G								H								I			J		
		Kanwaka sh.	Lecompton ls.	Tecumseh sh.	Deer Creek ls.	Calhoun sh.	Topeka ls.	Severy sh.	Howard ls.	Scranton sh.	Burlingame ls.	Willard sh.	Emporia ls.	Admire sh.	Americus ls.	Elmdale f.	Neva ls.	Eskridge sh.	Cottonwood ls.	Florena sh.	Neosho f.
FORAMINIFERA.																							
Ammodiscus concavus 376																	s						
Bigenerina cf. eximia 377																	s						
Dentalina bradyi 378																	s						
Fusulina sp. 88			A		A		A		X		G		A	G	C	A	A	X	A	A	X		
Fusulinella sp. 9																	s						
Lituola ?? sp. 275																	s						
Monogenerina atava 379																	s						
Monogenerina nodosariformis 380																	s						
Nodosaria postcarbonica 381																	s						
Schwagerina sp. 382																	s						
Tetraxis conica 383																	s						
Textularia gibbosa 384																	s						
SPONGIÆ.																							
Amblysiphonella prosseri 322							X																
Amblysiphonella sp. 68																							
Somphospongia multiformis 359											X												
Sponge sp. 69																							
Sponge sp. 71																							
ANTHOZOA.																							
Aulopora? anna 163																X							
Aulopora? prosseri 73																							
Axophyllum rude 13																							
Campophyllum torquium 53			X						X														
Chætetes milleporaceous 6																							

Cladochonus bennetti																				
Coral sp. 395																				X
Lophophyllum profundum 74		X		X		X	X	X				X		G	X	X		X	X	
Lophophyllum westii 22								X				?								
Michelinia eugeneae 145																				
Syringopora multattenuata 254						G														
CRINOIDEA.																				
Ceriocrinus craigi 280								X												
Ceriocrinus harshbargeri 341								X												
Ceriocrinus hemisphericus 61							X	X						?					X	
Ceriocrinus missouriensis 257																				
Ceriocrinus monticulatis 342								X												
Ceriocrinus noduliferus 256																				
Ceriocrinus ? sp. 395																				X
Cromyocrinus sangamonensis 255																				
Cyathocrinus stillativus 225																				
Erisocrinus megalobrachius 343								X												
Erisocrinus toddi 257																				
Erisocrinus typus 60																				
Eupachycrinus harii 258																				
Eupachycrinus magister 259																				
Eupachycrinus sphaeralis 260																				
Eupachycrinus tuberculatis 208																				
Hydreionocrinus acanthophorus 209																				
Hydreionocrinus discus 277																				
Hydreionocrinus mucrospinus 157						B														
Hydreionocrinus pentagonus 227																				
Hydreionocrinus subsinuatus 290																				
Phialocrinus basilicus 261																				
Phialocrinus brachydactylus 262																				
Phialocrinus harii 263																				
Phialocrinus lykensi 264																				
Phialocrinus magnificus 59																				
Scaphiocrinus washburni 344								X												
OPHIUROIDEA.																				
Ophiuroid 397																				X
ECHINOIDEA.																				
Echinocrinus aculeatus 90		?		X		C		X												
Echinocrinus edgarensis 368															X					
Echinocrinus megastylus 373															X		X		X	X
Echinocrinus spinoclavatus 369															X					
Echinocrinus triserratus 283															X					
Echinocrinus trudifer, 323						?														
Oligoporus ? ? minutis 319				X																
Pholidocidaris sp. 386																	X		X	

SYSTEMATIC CHART.—SECOND HALF.

Species.	Series III—*Concluded.*														Series IV.					
Stage ☞	G								H						I			J		
	Kanwaka sh.	Lecompton ls.	Tecumseh sh.	Deer Creek ls.	Calhoun sh.	Topeka ls.	Severy sh.	Howard ls.	Scranton sh.	Burlingame ls.	Willard sh.	Emporia ls.	Admire sh.	Americus ls.	Elmdale f.	Neva ls.	Eskridge sh.	Cottonwood ls.	Florena sh.	Neosho f.
FORAMINIFERA.																				
Ammodiscus concavus 376																S				
Bigenerina cf. eximia 377																S				
Dentelina bradyi 378																S				
Fusulina sp. 88		A		A		A		X		G		A	G	C	A	A	X	A	A	X
Fusulinella sp. 9																				
Lituola ?? sp. 275																S				
Monogenerina atava 379																S				
Monogenerina nodosariformis 380																S				
Nodosaria postcarbonica 381																S				
Schwagerina sp. 382																S				
Tetraxir conica 383																S				
Textularia gibbosa 384																S				
SPONGIÆ.																				
Amblysiphonella prosseri 322						X														
Amblysiphonella sp. 68																				
Somphosphongia multiformis 359										X										
Sponge sp. 69																				
Sponge sp. 71																				
ANTHOZOA.																				
Aulopora? anna 163															X					
Aulopora? prosseri 73																				
Axophyllum rude 13																				
Campophyllum torquium 53		X						X												
Chætetes milleporaceous 6																				

Cladochonus bennetti																				X
Coral sp. 395																				X
Lophophyllum profundum 74		X		X		X	X	X				X		G	X	X		X	X	
Lophophyllum westii 22								X				?								
Michelinia eugeneae 145																				
Syringopora multattenuata 254						G														
CRINOIDEA.																				
Ceriocrinus craigi 280								X												
Ceriocrinus harshbargeri 341								X												
Ceriocrinus hemisphericus 61							X	X						?					X	
Ceriocrinus missouriensis 257																				
Ceriocrinus monticulatis 342								X												
Ceriocrinus noduliferus 256																				
Ceriocrinus? sp. 395																				X
Cromyocrinus sangamonensis 255																				
Cyathocrinus stillativus 223																				
Erisocrinus megalobrachius 343								X												
Erisocrinus toddi 257																				
Erisocrinus typus 60																				
Eupachycrinus harii 258																				
Eupachycrinus magister 259																				
Eupachycrinus sphaeralis 260																				
Eupachycrinus tuberculatis 208																				
Hydreionocrinus acanthophorus 209																				
Hydreionocrinus discus 277																				
Hydreionocrinus mucrospinus 157						B														
Hydreionocrinus pentagonus 227																				
Hydreionocrinus subsinuatus 290																				
Phialocrinus basilicus 261																				
Phialocrinus brachydactylus 262																				
Phialocrinus harii 263																				
Phialocrinus lykensi 264																				
Phialocrinus magnificus 59																				
Scaphiocrinus washburni 344								X												
OPHIUROIDEA.																				
Ophiuroid 397																				X
ECHINOIDEA.																				
Echinocrinus aculeatus 90		?		X		C		X												
Echinocrinus edgarensis 368															X					
Echinocrinus megastylus 373															X		X		X	X
Echinocrinus spinoclavatus 369															X					
Echinocrinus triserratus 283															X					
Echinocrinus trudifer, 323						?														
Oligoporus? ? minutis 319				X																
Pholidocidaris sp. 386																	X		X	

Neuropteris scheuchzeri Hoffm. Pl. XLVI, fig. 8.

Neuropteris scheuchzeri Hoffman, in Kieferstein, vol. 4, p. 157, pl. 1*b*, figs. 1-4, 1826.

Neuropteris hirsuta Lesquereux, Boston Journal Science Nat. Hist., vol. 6, p. 417, 1854.

Neuropteris fasciculata Lesquereux (pars.), Geol. Report, Illinois, vol. 4, p. 381.

Neuropteris scheuchzeri in its varying forms is present in the Kansas Coal Measures from the Cherokee shales to the Garrison formation. The specimens from Lansing, 100 feet below the top of the Cherokee shales, are for the most part narrow, more or less distinctly pointed at the apex, in which respect they approach the form found at Clinton, Mo., and for which White has suggested the varietal name *angustifolia*. A few much larger pinnules occur at this locality, approaching in size *Neuropteris discipiens*, from which they are, however, separated by their finer nervation. The species is exceedingly abundant in the Le Roy and Scranton shales.

N. scheuchzeri differs from its nearest relative, *N. decipiens* Lesqx., by its more numerous veins, counting 35 to 45 and even 50 per centimeter, while *N. decipiens* has an average of 26 to 32 per centimeter; rarely as few as 22 or as many as 35. *N. decipiens* has also a much larger and more obtuse pinnule with stronger hairs. The constancy of these characters on many hundreds of specimens from the type locality of *N. decipiens* which I have examined appear to me sufficient reason for retaining, as White suggests, the two forms separate. Under the name *N. fasciculata* Lesquereux has apparently described and figured anomalous or cyclopterid pinnules of more than one species. As for the Mazon Creek representatives of *N. fasciculata* the several specimens that have come to my notice have presented quite uniformly the distinctive characters of *N. decipiens*. Other figured specimens appear to belong, in part at least, to *Neuropteris scheuchzeri*.

Mr. David White has given a careful description and full discussion of this species in Bulletin 98 of the United States Geological Survey, to which the reader is referred for a more detailed account. The terminal pinnule of the secondary pinna is peculiar. It is easily recognized by its elliptical shape, symmetrical and slightly cordate base attached to a pedicel-like extension of the rachis. These terminal pinnules are not infrequently found detached. Below the terminal pinnule is found one or more pairs of lateral pinnules, slightly petiolate,

Polypora flexuosa 278																				
Polypora missouriensis 312																				
Polypora nodocarinata 236			?	X																
Polypora spinulifera 316																				
Polypora submarginata 155						X														
Polypora triangularis 75																				
Prismopora serrata 178																				
Prismopora triangulata 10																				
Rhabdomeson americanum 285																		X	X	X
Rhombocladia delicata 27																				
Rhombopora lepidodendroidea 57			X	G		C	G	A		G	G			G	X	X	X	X	X	A
Rhombopora sp. 42																				
Septopora biserialis 43			X			X								?	X	X	X	X	X	C
Septopora interporata 246																				
Septopora multipora 271																				
Septopora pinnata 279				X																
Stenopora carbonaria 32			G												X				X	X
Stenopora ohioensis 265																				
Stenopora spinulosa 266																				
Streblotrypa prisca 91						C		A										X	X	X
Streblotrypa striatopora 282								X												
Thamniscus octonarius 107														X	X		X		C	A
Thamniscus tenuiramus 276																				
BRACHIOPODA.																				
Ambocoelia planoconvexa 5			G	C		X	A	C	G			C	G	A	A	C	G		X	
Aulacorhynchus millepunctatus 284										X	G				X					
Chonetes variolatus 113			G				G	G	G	G	G				G?					
Chonetes geinitzi 181							X	X			G				X	X				
Chonetes granulifer 76			X	C		A	C	A	X			X		C	C	X	X	X	A	C
Chonetes mesolobus 4																				
Chonetes verneuilanus 28							X							G						
Cleiothyris orbicularis 62																				
Crania modesta 105				X										X	X				C	X
Cryptacanthia compacta 63																				
Derbya bennetti 77						?														
Derbya broadheadi 315																				
Derbya crassa 17			G	C		X	X	C		X	G		G	X	X		X		C	X
Derbya keokuk 78			G	X		X		X	G								?			X
Derbya multistriata 108				G										X					X	C
Dielasma bovidens 26			G	X		X	X	X	G	X				X	X				X	X
Enteletes hemiplicata 70			G	X				X	G	C	G	X		G	X					X
Hustedia mormoni 25			G	G		C	C	X	X			X	G	A	C	X				
Lingula carbonari 130							G		G											
Lingula unbonata 92							C		X						X					
Marginifera longispina 12			G	X		C	A	A	G					G	X	X			?	
Marginifera muricata 1				G																
Meekella pyramidalis 288																				
Meekella striaticostata 64			G	X		X				X			G	G	X	X	X	G	C	C
Orbiculoidea convexa 188							X	X											X	X

SYSTEMATIC CHART—CONTINUED.

Species.	Stage	Series III—Concluded. G: Kanwaka sh.	Lecompton ls.	Tecumseh sh.	Deer Creek ls.	Calhoun sh.	Topeka ls.	Severy sh.	Howard ls.	H: Scranton sh.	Burlingame ls.	Willard sh.	Emporia ls.	Admire sh.	Americus ls.	Series IV. I: Elmdale f.	Neva ls.	Eskridge sh.	J: Cottonwood ls.	Florena sh.	Neosho f.
BRACHIOPODA—CONCLUDED.																					
Orbiculoidea manhattanensis 370							X	A		X						X					?
Orbiculoidea missouriensis 18																					
Proboscidella sp. 41																					
Productus auriculatus 137			X				C	X			X	G	X	G	C	X				X	
Productus cora 19						X	X	X	X			G	X	G	C	X					
Productus costatus 39			X				C	X	X	X	G	G	X	G	X	X	X	C		C	A
Productus nebraskensis 44			X				X	X	X		G	G	X	G	X						
Productus pertenuis 14			G				C	X	C	G	X										
Productus punctatus 8			G				C	X	C		X		X	G	X	X	X	G	G	A	X
Productus semireticulatus 7							C	X	C	G			X	G	X	X					
Productus symmetricus 242																					
Pugnax rockymontana 179								X	X					G	C	C	C			X	X
Pugnax utah 79								C	X					G	C	X	A	X	G	A	X
Rhipidomella pecosi 54			X				A	C	A	X	C		X	G	C	C					
Seminula argentea 3			X				A	C	A	X	C		X	G	C	C	C				
Seminula subquadrata 173							C	X	C	G	G	G	X	G	C	X					
Spirifer cameratus 11			X				C	X	C	G	G	G	X			X					
Spirterina kentuckiensis 30							C	X	C												
Squamularia perplexa 2			X				C	X	X						X	X	X	X			
Strophalosia sp 89																					
Strophalosia spondyliformis 144																					
PELECYPODA.																					
Allorisma costatum 116									X		X				G	X					X
Allorisma geinitzi 356									X		X				G	X					
Allorisma ? kansasensis 345									X			G									
Allorisma terminale 94			B			X		X	X		C	G				X	X	X		X	X

Astartella gurleyi 835
Astartella varica 117
Astartella vera 177
Aviculopecten carboniferus 34
Aviculopecten coxanus 237
Aviculopecten germanus? 297
Aviculopecten hertzeri 200
Aviculopecten interlineatus 114
Aviculopecten maccoyi 186
Aviculopecten occidentalis 35
Aviculopecten providencensis 151
Aviculopecten? rectilateralis 115
Aviculopecten? sculptilis 255
Aviculopecten whitei 340
Aviculopinna americana 268
Aviculopinna illinoiensis 183
Aviculupinna nebraskensis 374
Cardiomorpha missouriensis 331
Chaenocardia ovata 313
Chaenomya cooperi 243
Chaenomya leavenworthana 205
Chaenomya maria 398
Clinopistha radiata 170
Clinopistha radiata laevis 336
Conocardium acadianum 138
Conocardium obliquum 241
Conocardium parishi 147
Crenipecten winchelli 210
Cypricardinia carbonari 45
Edmondia aspenwallensis 95
Edmondia nebraskensis 80
Edmondia ovata 360
Edmondia reflexa 185
Entolium aviculatum 118
Euchondria neglecta 166
Leda arata 327
Lima retifera 190
Lima krotowi 149
Limopteria alata 230
Limopteria gobbosa 239
Limopteria longispina 81
Limopteria marian 82
Limopteria subalata 295
Macrodon carbonarius 365
Macrodon obsoletus 244
Macrodon sangamonensis 197
Macrodon tenuistriatus 129
Microdon oblonga 211
Modiola? subelliptica 245
Myalina ampla 208

SYSTEMATIC CHART—CONTINUED.

SPECIES.	Stage	SERIES III—Concluded. G: Kanwaka sh.	Lecompton ls.	Tecumseh sh.	Deer Creek ls.	Calhoun sh.	Topeka ls.	Severy sh.	Howard ls.	SERIES III—Concluded. H: Scranton sh.	Burlingame ls.	Willard sh.	Emporia ls.	Admire sh.	Americus ls.	SERIES IV. I: Elmdale f.	Neva ls.	Eskridge sh.	SERIES IV. J: Cottonwood ls.	Florena sh.	Neosho f.
PELECYPODA—CONCLUDED.																					
Myalina aviculoides 372																C?					
Myalina congeneris? 358										?											
Myalina? exasperata 332					X			X	X												
Nyalina kansasensis 109			G														X			X	C
Myalina perattenuata 101					X			X	X	X	X							C			X
Myalina permiana 102																					
Myalina recurvirostris 233																					
Myalina subquadrata 29			G		G		G	X	G	X	X	G									
Myalina swallowi 46					X		X	X	X	X								X		X	C
Myalina wyomingensis 318			G																		
Nucula beyrichi 399																					?
Nucula parva 212																					
Nucula pulchella 291																		X			
Nucula sp 385					G			C	G				C							X	X
Nucula ventricosa 20								C	C	X						X		C		X	X
Nuculana attenuata 21								X													
Naculana bellistriata 159																					
Pinna lata 346			X		X		X	X	X	X	X										X
Pinna peracuta 189					?																
Pinna subspatulata 320									X												
Placunopsis carbonaria 347																					
Pleurophorus angulatus 213																					
Pleurophorus oblongus 214																					
Pleurophorus occidentalis 344													G?								
Pleurophorus subcostatus 110																					C
Pleurophorus tropidopherus 202										X											
Pleurophorus whitei 375																X				X	X
Posidonomya? pertenuis 292																					

SYSTEMATIC CHART—CONTINUED.

Species.	Series III—*Concluded.*														Series					
Stage ☞	G								H						I			J		
	Kanwaka sh.	Lecompton ls.	Tecumseh sh.	Deer Creek ls.	Calhoun sh.	Topeka ls.	Severy sh.	Howard ls.	Scranton sh.	Burlingame ls.	Willard sh.	Emporia ls.	Admire sh.	Americus ls.	Elmdale f.	Neva ls.	Eskridge sh.	Cottonwood ls.	Florena sh.	Neosho f.
GASTROPODA—CONCLUDED.																				
Euomphalus catilloides 165				G		X	X	X	X	G				X	X	?	X		X	X
Euphemus carbonarius 133						X	G	X	X	X							X		X	X
Euphemus nodocarinatus 182																				
Loxonema rugosum 142																				
Murchisonia nebraskensis 103																	C			X
Naticopsis altonensis 162							G	X				?								
Naticopsis monilifera 216																				
Naticopsis ventricosa 161								X												
Orthonema salteri 310																				
Orthonema subtæniatum 333							X													
Patellostium bellum 50							?					?								
Patellostium montfortianum 134							G	X		X					G		?			X
Patellostium textiliforme 221																				
Phanerotrema grayvillensis 180						G	X	G												
Platyceras nebraskensis 287																				
Pleurotomaria bonharborensis 234																				
Pleurotomaria brazoensis 131												?								
Pleurotomaria broadheadi 141																				
Pleurotomaria carbonaria 112																				
Pleurotomaria conformis 217																				
Pleurotomaria coxana 218																				
Pleurotomaria inornata 219																				
Pleurotomaria perhumerosa 96							X					A								
Pleurotomaria scitula 119																				
Pleurotomaria subdecussata 93							C		X											
Soleniscus? anguliferus 334							?													
Soleniscus paludinæformis 361										X										
Sphærodoma intercalaris 135																				?

Sphærodoma medialis 357								X													?
Sphærodoma ponderosa 289																					
Sphærodoma toxana 362										X											
Strophostylus nanus 132							X	X				X									
Trachydomia nodosum 220																					
Trachydomia wheeleri 184		G		X																	
Trepospira illinoisensis 338							X	?													
Trepospira spherulata 128							X														
Worthenia speciosa 143																					
Worthenia tabulata 176				X			G	X													
PTEROPODA.																					
Conularia crustula 56				?																	
CEPHALOPODA.																					
Asymptoceras capax 193																					
Asymptoceras newloni 120																					
Agnides sp. 366												X									
Coloceras cf. globatum 194																					
Domatoceras lasallense 199																					
Domatoceras umbilicatum 121																					
Endolobus missouriense 222																					
Ephippoceras divisum 140																					
Ephippoceras ferratum 153																					
Gastrioceras subcavum 350								X													
Gastrioceras sp. 97												C									
Metacoceras sangamonense 187								X													?
Nautilus plauorbiformis 169																					
Nautilus planovolvis 160								X													
Nautilus toddi 223																					
Orthoceras cribosum 136							X														?
Orthoceras muntrianum 314																					
Orthoceras rushense 167							G	?													P?
Solenocheilus sp. 351								?													
Stearoceras gibbosum 352								?													
Tainoceras occidentale 168								X		X											
Temnocheilus crassus 122																					
Temnocheilus depressus 123																					
Temnocheilus latus 124																					
Titanoceras ponderosum 195																					
TRILOBITA.																					
Griffithides scitula 16				X		X	X	X							X		X	X	X	X	
Phillipsia major 156		G				X															
Phillipsia nodocostatus 224																					

SYSTEMATIC CHART—CONCLUDED.

SPECIES.	SERIES III—*Concluded.*														S					
Stage	G								H						I			J		
	Kanwaka sh	Lecompton ls.	Tecumseh sh.	Deer Creek ls.	Calhoun sh.	Topeka ls.	Severy sh.	Howard ls	Scranton sh.	Burlingame ls	Willard sh.	Emporia ls	Admire sh.	Americus ls.	Elmdale f.	Neva ls.	Eskridge sh	Cottonwood ls	Florena sh.	Neosho f.
OSTRACODA.																				
Bairdia beedei 104														X			C		A	X
Bairdia beedei abrupta 106																	X		C	X
Beyrichia? emaciata 391																			X	X
Beyrichia haworthi 388																			X	
Beyrichia radiata 392																			X	X
Beyrichiella bolliaformis 393																			X	X
Beyrichiella bolliaformis tumida 367														X					X	X
Cypridella americana 15																				
Cypridella sp. 33																				
Cypridina subovata 154																				
Cypridinella sp. 150																				
Entomis sp. 172																				
Kirbya centrornata 389																			X	
Kirbya pinguis 394																			X	X
Paraparchites humerosus 100															A				X	
MEROSTOMATA.																				
Cyclus communis 67																				
Cyclus limbatus 272																				
Cyclus minutus 273																				
Cyclus packardi 148																				
Cyclus permarginatus 274																				
Prestwichia danæ 235																				
INSECTA.																				
Ectoblattina Gen. et sp. nov. 85																				
Etoblattina coreacea 300																				

Etoblattina juvenalis 299																				
Etoblattina occidentalis 301																				
Etoblattina sp. 302																				
Gerablattina arcuata 303																				
Hænoblattina sp. 304																				
Hænoblattina sp. 305																				
Schizoblattina multinerva 306																				
Schizoblattina sp. 307																				
Spiloblattina maledicta 87																				
Spiloblattina sp. 308																				
Spiloblattina sp. 309																				
VERTEBRATA.																				
Sagenodus copeanus 337										X										
Agassizodus variabilis 386							X													
Cladodus mortifer 390																			X	
Cruricepa parva 250																				
Duovestigia scala 251																				
Lystracanthus hystrix 55																				
Notalacerta jacksonensis 252																				
Notalacerta missouriensis 253																				
Notamphibia major 249																				
Peripristis semicircularis 175						X		X												
Petalodus ohioensis 238								X												
Petrodus occidentalis 139																				
Punctatumvestigium circuliformis 248																				

Sigillariastrobus.

Sigillariastrobus sp.

Sporangiophores obovate, close, 4 to 6 mm. long, 3 mm. wide, club-shaped, short pedicellate, largest at the upper end. Cone flattened by crushing. The sigillara cones of this type are numerous in the abandoned coal-mine at Blue Mound, in association with stems of *Sigillaria*. They reach a considerable length—as much as a foot or more. Not infrequently the macrospores are preserved in place.

Formation and locality: Le Roy shales at Blue Mound.

Sporangia, detached.

Two specimens from the Le Roy shales at Blue Mound show numerous clusters of sporangia detached and lying alongside a rachis. They were apparently attached to the rachis by a short pedicel. The sporangia are in clusters of fours, united at the base. They are about 1 mm. in length, the free ends being pointed. The cluster of sporangia is square in cross-section at the base. The rachis on which from their position they seem to have been borne, is slender, striated, and without attached leaflets.

EQUISETALES.

CALAMARIEÆ.

Calamites SUCKOW.

Calamites ramosus Artis.

This species is rather abundant in the Le Roy shales.

Calamites suckowii Brongn.

Formation and locality: Found at Lansing, and very abundant in the Le Roy shales; also present in the Scranton shales at Scranton.

Calamites cistii Brongn.

This species is not uncommon in the Le Roy shales at Lawrence.

Asterophyllites BRONGNIART.

Asterophyllites equisetiformis (Schloth.) Brongn.

Formation and locality: Found in the Cherokee shales at Lansing, Chanute shales at Thayer, and in the Le Roy, Lawrence and Scranton shales. The few specimens observed from Lansing are all of a less robust type than is common in the higher formations. The species has also been obtained by

Chanute Shales.—The University museum contains a small collection of plants from the Chanute shales, at Thayer.

DOUGLAS STAGE.

Le Roy and Lawrence Shales.—The collections from the Douglas formation have been made from the following localities: Blue Mound, six miles southeast of Lawrence; Haverkampf farm, three miles southeast of Lawrence; Deer Creek, twelve miles west of Lawrence; Baldwin, Ottawa, and Twinmound.

SHAWNEE STAGE.

Scranton Shales.—Small collections of plants have been made from the coal-mines in the Scranton shales, at Scranton, Burlingame, and Osage City.

WABAUNSEE STAGE.

Willard Shales.—The light-colored clayey shales exposed along the west branch of a small tributary to the Neosho river, one and one-half miles northwest of Emporia, contains a limited flora, from which a small collection was made.

Admire Shales.—A small collection of plants was made from the Admire shales on Reservoir Hill, two and one-half miles northwest of Emporia. The plants are found mostly from one to a few feet below a ten-inch vein of coal.

Elmdale Formation.—Mr. David White has very kindly sent for study an interesting series of the enigmatic fossil *Daubreeia* Zeiller from the Elmdale formation, at Onaga, Kan. A small collection has also been obtained from this formation one mile northwest of Reece.

COUNCIL GROVE STAGE.

Garrison Formation.—A very carbonaceous shale, about 30 feet above the base of the Garrison formation, exposed at the mouth of a tributary to the Neosho river, three miles southeast of Council Grove, has furnished a limited number of species.

CHASE STAGE.

Wreford Limestone.—The light sandy shales within the Wreford limestone formation and about fifteen feet from the base, as exposed in the Missouri Pacific railroad cut, seven miles west of Reece, has yielded an extremely interesting small assemblage of plants. During the summer of 1906 well-preserved plants were found by the Kansas Survey party six miles north and one mile east of Washington, Kan. This locality is re-

ed by Dr. J. W. Beede, who was in charge of the party, as p ably somewhat above the Winfield limestone.

SUMNER STAGE.

Wellington Shales.—An interesting plant horizon has been discovered in the Wellington shales, from which four collections have been made—the first by Mr. Charles Sterling, the remaining three by the writer. The horizon is near the top of the formation in Dickinson county. The principal locality is three and a half miles south of Banner City, and within a few feet of the overlying Cretac small lot of plants was also obtained from a locality four miles south of Carlton, and another from a mile east of Salina along the east bank of the Smoky Hill river, in the section referred doubtfully to the Wellington by Prosser (vol. 2, p. 68).

The Banner City locality when first discovered was considered as probably in the Marion formation. The possibility of the locality lying within the Wellington was however recognized (Trans. Kan. Acad. Sci., vol. XVII, 1900, p. 208). The stratigraphy of this section was worked out in more detail by Dr. J. W. Beede during the summer of 1908, and the present reference of the locality to the Wellington is in accordance with the correlations given in this volume.

Acknowledgments.

The following report on the Kansas Carboniferous and Permian plants was begun in 1899 and has been added to from time to time as opportunity afforded. Very important additions to the literature of fossil botany have been made since the earlier pages of the manuscript were written. The results of these later papers touching the species here described have been included whenever possible. The time at the writer's disposal, however, does not admit of as complete a revision of the manuscript preceding its publication as could have been desired, and the paper can hardly fail to give evidence of its disconnected preparation. The study was begun at the suggestion and under the direction of Prof. S. W. Williston, then paleontologist to the Kansas State Geological Survey, whose interest and encouragement in the work it is a pleasure to acknowledge. During the writer's stay at the Yale Museum, 1901-1903, Dr. Alexander W. Evans very materially assisted him in the comparative study of related recent plants. The late Prof. C. E. Beecher also very kindly made accessible the fossil-plant col-

lections of the Yale Museum, among which those from Clinton, Mo., and the unparalleled representation of the Mazon Creek flora have been of especial value because of their relation to the lowermost divisions of the Kansas flora. Professor Beecher's well-known unfailing interest wherever fossils are concerned, and his advice and direction, have added much to the results of the study. The writer has been repeatedly indebted from the beginning of these studies to Mr. David White, paleobotanist to the United States Geological Survey, for reference to literature and for advice in the determination of specimens, as well as for access, often at not a little inconvenience to himself, to the extensive plant collections of the National Museum. The later additions to the collections and review of the stratigraphy of the Permian formations, as well as the completion and publication of the paper, has been made possible by the interest in the work and the opportunities afforded the writer by Professor Erasmus Haworth, Geologist of the State Survey. The line drawings were made largely by Mr. S. Prentice.

THE COAL MEASURES FLORA.

Description of Genera and Species.

PTERIDOPHYTA.

FILICALES.

SCHIMPER.

1, p. 416, 1869.

Eremopteris solida [illegible] XLIV, fig. 11; pl. LVII, fig. 2.

Sphenopteris soli [illegible] Coal Flora, vol. 3, p. 769, pl. 101, fig. 3, 1884.

Eremopteris solida (Lesqx.) [illegible]., Bull. U. S. G. S. No. 211, p. 88, 1903.

The specimen referred to [illegible] species agrees very closely with examples of *Sphenopteris* [illegible]*lida* from the type locality at Mazon Creek, Illinois, with [illegible]h I have compared it. The pinnules are long and deeply [illegible]e. The venation is obscured, except at the bases of the pin[illegible] and in the lobes. Fine striæ are sometimes visible in the epidermis. The plant is much like *E. bilobata*, from Clinton, Mo., which White has provisionally separated as a distinct species.

Formation and locality: A few specimens have been obtained from the State Penitentiary mine at Lansing, Kan., about 100 feet below the top of the Cherokee shales.

Eremopteris missouriensis Lx. Pl. XLIV, fig. 12; pl. LVII, fig. 2.

Eremopteris missouriensis Lesquereux, Coal Flora, vol. 1, p. 295, 1880; atlas, pl. 53, figs. 8, 8*a*, 1879.

Eremopteris missouriensis Lx., David White, Flora of the Lower Coal Measures of Missouri, p. 16, pl. 5, figs. 1-3; pl. 6, 1899.

The single fragment which I refer to this species has pinnules larger, more distant, the lobes broader, than those of the type specimens or those from Missouri figured by White (*loc. cit.*) The nervation, so far as it can be made out in the thick epidermis, agrees with the types. The midvein of the pinnules is seen to be decurrent at the base to the flat, winged rachis, forked and sending branches into the obtuse, or sometimes bifid, lobes. The character of the lamina, roughened and finely lineate with short scales, is very similar to that of the Missouri specimens.

Formation and locality: Cherokee shales, Lansing, Kan.

Pseudopecopteris LESQUEREUX.
Coal Flora, vol. 1, p. 189, 1880.

Pseudopecopteris cf. dimorpha Lx. Pl. XLIV, figs. 2, 3; pl. LVI, fig. 1.

Fronds dense, leaving a thick carbonaceous layer on the shale. Ultimate pinnæ ovate-lanceolate, alternate, close, ½ to 1½ cm. apart, sessile, often overlapping, gradually reduced in passing to the apex of the frond. Pinnules also crowded, alternate, often overlapping, attached by the entire base, open, or oblique, irregular in shape, variously lobed or entire, according to their position on the frond. Basal pinnules 8 to 12 or more mm. long, divided into three to five ovate or elongate lobes, the first of which on the lower side projects over the rachis to which the pinnule is attached. Pinnules gradually reduced in passing to the top, becoming near the apex of the pinna smaller, less deeply lobed, ovate, the lobes partly confluent with the small terminal lobe. Pinnules near the middle of the pinna constricted at the middle, enlarged at the base and to some extent at the apex. The substance of the pinnule is thick, the veins thin and immersed in the epidermis. A midvein is traceable to about or above the middle of the pinnule. The lateral veins go off at a sharp angle and curve to the borders, dichotomizing two, three or more times; veins numerous, fine, and very thin, being almost hidden in the thick leaf substance. The species is as yet incompletely known, only a few specimens having been obtained, and the comparison with *P. dimorpha* is provisional.

Formation and locality: Lawrence shales, Twinmound, Upper Coal Measures.

Pseudopecopteris pluckenetii (Schloth) Lx. Pl. XLIV, fig. 1.

Felicites pluckenetii Schlotheim, Flora der Forwelt, pl. 10, fig. 9, 1804.

Pseudopecopteris pluckenetii (Schloth.), Coal Flora, p. 199.

The Kansas specimens of this species indicate that the complete fronds were very large. The main rachis of the frond is strong, woody, 22 mm. wide. The primary pinnæ go off from the main rachis at right angles. The rachises of the pinnæ are strong, 20 mm. wide at their union with the main rachis, and striate with undulating woody fibers. The rachises are throughout round, striated, and, except those of the primary and secondary pinnæ, bordered by a wing-like extension of the lamina. The divisions of the frond are almost or quite at right angles, or very slightly inclined; the pinnæ are rather distant,

always clearly separated from each other, linear to narrowly ovate-lanceolate. The venation is indistinct. The midvein of the ovate pinnules enters the lobe near the lower side, gives off one or two veins from either side and divides somewhat above the middle of the pinnule. The veins are few and rather distant.

Pecopteris germari (Weiss) F. and I. C. W., which has a frond with divisions similar to this species, lacks, as indicated by Weiss,[281] as well as by Fontaine and White,[282] the winged character of the rachis. The species has much in common with *Pecopteris beyrichi* (Weiss) Zeiller.

Many of the specimens are thickly set with the supposed fungus *Excipulites neesii* Goep.

Formation and locality: Chanute shales, Thayer, and Le Roy shales, Lawrence. Mr. David White records the presence of this species in the Cherokee shales at Lansing (Bull U. S. Geol. Surv. No. 211, p. 110, 1903).

Pseudopecopteris obtusiloba (Brongn.) Lx. Pl. LIV, figs. 2, 4.

Sphenopteris obtusiloba Brongniart, Hist. Veg. Foss., p. 20, pl. 53, fig. 2, 1829.

Pseudopecopteris obtusiloba (Brongn.) Lesquereux, Coal Flora, vol. 3, p. 753, 1884.

This species is present, although not common, at the State Penitentiary mine, at Lansing. A few good typical specimens have, however, been obtained.

Formation and locality: Cherokee shales, Lansing.

Pseudopecopteris squamosa (Lx.) D. W.

A single specimen from Lansing is referred doubtfully to this species.

Formation and locality: Cherokee shales, Lansing.

Mariopteris ZEILLER.

Bull. Soc. Geol. France, ser. 3, vol. 8, p. 93, 1878.

Mariopteris obtusiloba D. W. var. Pl. XLV, fig. 20; pl. XLVI, figs. 1-5; pl. XLVIII, fig. 13; pl. XLIX, fig. 2; pl. LV, fig. 2.

Pseudopecopteris cordato-ovata Weiss, Lesquereux, Coal Flora, vol. 1, p. 205, pl. 37, figs. 4, 5, 1889.

Mariopteris cordato-ovata obtusiloba D. W., Bull. No. 211, U. S. G. S., p. 89.

Fronds bipinnate or more. Rachis smooth or finely lineate, flat or nearly so. Ultimate pinnæ alternate, oblique, linear, obtuse at the apex. Pinnules alternate, oblique or open, decur-

281. Flora der Jungst. Steinkohlen Formation, pl. 12, fig. 4, p. 67.

282. Permian Flora, p. 68, pl. 19, figs. 1-7.

rent, cut in above the base by an acute sinus, oblong-ovate, obtusely pointed, broadest just above the base, united by a wing-like membrane bordering the rachis. Lower basal pinnule of the pinna often heteromorphous, lobed, the lower one deflexed along the rachis. Texture thin but somewhat coriaceous. Venation often indistinct, midvein decurrent at the base, continuing to near the apex; lateral veins oblique, only moderately curved, forked once or twice at a rather narrow angle.

This fern was referred by Lesquereux to the European species *Sphenopteris* (*Neuropteris*) *cordato-ovata* (Weiss) Zeiller. The identity of the American and European forms has, however, been questioned by Zeiller, White, and others. The species is abundant in the Le Roy shales, and the large series of specimens differ uniformly from the types figured by Weiss in the more obtuse pinnules, which are much broader in proportion to their length. The rachis of the pinna projects beyond the lamina, and the basal pinnule on the lower side is deflexed and heteromorphous, characters apparently absent from the *Sphenopteris cordato-ovata* as figured by European authors, and which necessitate the reference of the species to the genus *Mariopteris*.

Formation and locality: Le Roy shales, Upper Coal Measures. Occurs also at Thayer, according to White (Bull. U. S. Geol. Surv. No. 211).

Mariopteris occidentalis D. W. Pl. XLIV, fig. 4.

Mariopteris occidentalis David White, Nineteenth Annual Report of the U. S. Geol. Surv., pt. III, Fossil Plants of the McAlester-Lehigh Coal Field, Ind. Ter., p. 480, pl. 67, figs. 1-6, 1899.

The presence of this species in the Cherokee shales at the Lansing mine seems assured, although the material representing it consists of a single specimen, the upper part of an ultimate pinna. The agreement, however, with the original description and illustrations, as well as with specimens from the type locality, is so close that there can be little doubt of its reference. The nervation of the specimen is very clearly preserved in detail.

Formation and locality: Cherokee shales, Lansing, Kan.

Sphenopteris BRONGNIART.

Filicites sec. *Sphenopteris* Brongniart, Mem. Mus. Hist. Nat., vol. 8, p. 233, 1822.

Sphenopteris cf. biturica Zeiller. Pl. XLIV, figs. 6-8; pl. LVIII, fig. 2.

Fronds tri- or quadripinnate. Rachis woody, finely striated. Penultimate pinnæ alternate, oblique, going off at an angle of about 45 degrees, lanceolate-pointed. Rachis prominent, round, and winged in its upper part by a narrow membrane. Ultimate pinnæ alternate, oblique, broadly lineate, obtuse, nearly sessile, divided by acute shallow sinuses into numerous pointed, forward-projecting lobes, and ending in a very small terminal pinnule. Ultimate pinnæ passing into pinnules above, becoming at the top connate with the small terminal pinnule. Midvein of the small ultimate pinnæ decurrent; lateral veins distant, oblique, nearly straight, and running to the apex of the lobes, simple or once or twice forked. In general habit this fern has a likeness to Zeiller's species with which it is compared. The figures given by Zeiller in Flore de Brive as *S. decheni* are much like the Kansas plant, but the types of *S. decheni* as figured by Weiss are clearly distinct.

Formation and locality: Le Roy shales, Upper Coal Measures.

Sphenopteris sp. Pl. XLIV, figs. 9, 10.

Some specimens of a very delicate *Sphenopteris* have been obtained from the Le Roy shales. The species is remarkable for the wide angle at which the veins fork, and the flexuous character of the midvein.

Sphenopteris pinnatifida (Lx.) D. W. Pl. XLIV, fig. 5; pl. LIV, fig. 3.

Hymenophyllites pinnatifidus Lesquereux, Report Geological Survey Illinois, vol. 2, p. 436, pl. 34, figs. 2, 2*a*, 1866.

Sphenopteris (*Hymenophyllites*) *trydactylites* (Brong.) Lesquereux, Coal Flora, vol. 1, p. 284, pl. 55, figs. 9, 9*b*, text, 1880; atlas, 1879.

Sphenoteris pinnatifida (Lx.) D. W. David White, Flora of the Lower Coal Measures of Missouri, p. 45, pl. 18, figs. 3, 4; pl. 19, fig. 1, 1899.

Several of the Kansas specimens show small punctæ on the rachises of the secondary and tertiary pinnæ; these are distantly placed, as remarked by Lesquereux (Coal Flora, p. 285), scarcely visible to the unaided eye, not always distinct even with a lens, sometimes apparently not present. A large slab of shale from Thayer, Kan., containing parts of this species and of *Aloiopteris winslovii* D. W., has an instructive specimen showing the at least quinquepinnate character of *S. pinnatifida.*

The rachis of the primary (?) pinna is 6 mm. wide, finely lineate, punctæ not present, apparently not strongly woody; thin and flat in the fossil condition, curved upward, thus indicating that it is not the primary rachis of the frond. The secondary pinnæ are distant, at right angles, marked with distantly placed fine punctæ; the tertiary pinnæ are alternate, oblique, separated by a distance of 3 to 4 cm. The quaternary pinnæ are 4 to 10 mm. apart, 1 to 2 cm. long, and overlap somewhat. The ultimate pinnæ are 2 to 5 mm. apart, the pinnules variously lobed as described for the species. Another specimen on the same slab shows a secondary pinna with a very flexuous rachis, about 3 mm. wide, bending to meet the insertion of each of the tertiary pinnæ. The first quaternary pinna on the lower side is reflexed, lying close to and partly across the rachis of the secondary pinna.

Formation and locality: Cherokee shales, Lansing; Chanute shales, Thayer; Le Roy and Lawrence shales, Lawrence.

Aloiopteris POTONIE.

Jahrb. d. k. Geol. Landesanst. u. Bergakad., vol. 14, 1893.

Aloiopteris (?) aquatica sp. nov.

A few specimens have been obtained from the Lawrence shales which are apparently referable to an interesting new species. The largest pinna found has pinnules 1 to 2 cm. long, linear, alternate or subopposite, almost at right angles to the rachis, and divided into alternate ovate lobes standing out at right angles, the incisions between being broad and obtuse. The pinna and pinnules have a lax, flexuous appearance. The midvein of the pinnule is flexuous, and the lateral veins run out obliquely into the lobes, send off two or three branches, and themselves dichotomize near their termination. The veins are thick and flexuous, stand out distinctly from the thin leaf substances, and end in minute projecting teeth. The rachis of the pinna is flat, ribbon-like and flexuous, bordered by a thin membrane. The most striking character of the species is its thin, lax appearance.

Formation and locality: Twinmound, Lawrence shales, Upper Coal Measures.

is winslovii D. W. Pl. XLIV, figs. 13-17.
pteris winslovii D. W., Lower Coal Measures of Missouri, p. , pl. 22; pl. 23, figs. 1-5, 1899.

s bipinnate, or possibly more. Rachis of the frond trong, marked with large circular or irregularly punctæ, ½ to 1 mm. wide. Primary (?) pinnæ alter- right angles, linear or linear elliptical, contracted y at the base, obtuse at the apex, bearing abnormal or -like pinnules at the base. Rachis finely lineate, some- having small punctæ of the character of those of the n rac iate, close, or a little dis- tant, free, 5 to 15 n..... a , linear, obtusely rounded at the apex, slightly decurrent base, 2 to 12 or more cm. long, 3 to 7 mm. wide, oblique, or t right angles or reflexed, borders divided into small segmented lobes by obtuse or acute decurring sinuses; larger pinnæ clearly distinct at the base, passing toward the apex into linear, oblique pinnules, 1 to 3 or 4 cm. long, connate by the decurring lamina. Ultimate pinnæ toward the base of the primary pinnæ reduced, 1 or 2 cm. long, reflexed at an angle of about 45 degrees. Rachis flat or obtusely rounded below, covered with a fine, scaly lamina, slightly decurrent at the base. Lateral nerves at a very open angle, strong, curved slightly at the base, simple, or forked once or twice, ending in the tips of the segments.

A large slab from Thayer is partly covered with this species, and shows the linear, serrate pinnules borne on a thick rachis. The pinnules are alternate, close, 4 to 8 mm. apart, open, many of them curving back, narrowly linear, slender, sloping a little from the base to the obtuse apex, 2 to 7 cm. long. The large pinnules are clearly distinct, not united or decurring at the base. Near the apex of the pinna, however, the small pinnules are united by a decurring wing. The midrib is comparatively strong and continues to the apex. The lateral nerves are very open, curving more or less from the midrib to the border, forked once in the smaller pinnules, usually twice in the larger. The essential characters separating this species from *A. erosa* are apparently the broader and larger pinnules, with veins much more open, forking near the border.

Formation and locality: Le Roy shales, Blue Mound; Lawrence shales, Twinmound; Chanute shales.

Pecopteris BRONGNIART.

Filicites sec. *Pecopteris* Brongniart, Mem. Mus. Hist. Nat., vol. 8, p. 233, 1822.

Pecopteris vestita Lx. Pl. XLV, figs. 10-13.

Coal Flora, vol. 1, p. 252, pl. 43, figs. 1-7.

This species is rather abundant in the Cherokee shales. The midvein of the pinnule is but slightly decurrent at its union with the rachis. The lateral veins are open, fork once near the middle at a wide angle, the upper division sometimes again branched. The surface of the pinnule is very densely covered with scaly hairs, the venation, except where the pinnule was macerated somewhat before fossilization, being entirely obscured. The epidermis is capable, however, of being removed with acid, thus exposing the venation (plate XLV, fig. 11). The species is readily distinguished from *P. pseudovestita*, as characterized by David White, by the more distant nervation and the scaly epidermis. After comparing a large series of the specimens of this species as developed at Lansing with the form so abundant at Mazon Creek known in literature as "*P. villosa*," I am inclined to doubt the existence of sufficient characters to warrant the specific separation of the two forms. The pinnules of the species as developed at Lansing seem to be less decurrent, except in the small pinnules near the apex, than is the case in the specimens from the type locality at Clinton, Mo., in which character the Lansing plants approach the Mazon Creek form. In case the two forms are united as a single species Lesquereux's name should stand, as the *P. villosa* of Brongniart is a dubious species, and according to Kidston (Trans. Royal Soc. Edin., vol. 33, pt. 2, p. 37, 1886-'87) of doubtful existence.

Formation and locality: Cherokee shales, Lansing.

Pecopteris candolliana Brongn. Pl. XLV, figs. 6-9.

Pecopteris candolliana Brongniart, Hist. Veget. Foss., p. 305, pl. 100, figs. 1, 1*a*., 1833 or 1834; Lesquereux, Coal Flora, p 243; Geol. Rept. Ill., vol. 4, p. 401; Schimper, Pal. Veget. 1, p. 500; Potonie, Flora d. Roth. v. Thur., p. 99, pl. 7, figs. 4, 5, 1893.

Pecopteris candollei Brongn., Zeiller, Flora de Brive, p. 13, pl. 5, figs. 1-5.

Numerous specimens of this species are found in the concretionary nodules at Twinmound. The preservation is good and the venation distinct. The pinnæ are usually detached. The agreement with the European figures and descriptions of the species seems complete. The pinnules are at right angles, or only slightly inclined, somewhat unequal in length, linear,

angle of 45 to 60 degrees, lower veins arising directly from the rachis.

The larger pinnæ of this species reach a length of 20 cm. The pinnules of these large pinnæ are but slightly or not at all connate at the base. Near the tip of the pinna the pinnules become connate and decurrent at the base. The pinnules are irregular in size, shape and inclination to the rachis. As a rule, the basal pinnules are deflexed. The midvein is strong and continues to near the apex, where it terminates suddenly. The lateral veins fork once near the midvein. Occasionally they are simple.

Formation and locality: This species is abundant in the Le Roy shales, and has been obtained from the Scranton shales at Scranton. Mr. White (Bull. U. S. Geol. Survey No. 211, p. 112) records its presence at Thayer.

Callipteridium WEISS.

Callipteridium sullivantii Lx. Pl. L, figs. 1, 2; pl. LX, fig. 1.

Callipteridium sullivantii Lesquereux, Bost. Soc. Nat. Hist., vol. 6, No. 4, p. 423, 1854.

This species is present in typical form at Lansing in the Cherokee shales. The large pinnæ have pinnules irregular in size and shape, some being broad and short while others are more slender and longer.

Formation and locality: Cherokee shales, Lansing.

Callipteridium sp. Pl. XLV, fig. 22.

An undetermined species of *Callipteridium* occurs at the Haverkampf locality in the Le Roy shales. The pinnules are found occasionally in the concretions from that locality.

LYCOPODIALES.

SIGILLARIACEÆ.

Sigillaria BRONGNIART.

Mem. Mus. Hist. Nat., vol. 8, p. 209, 1822.

Sigillaria brardii Brong. Pl. LI, fig. 8; pl. LVII, figs. 1, 3.

Sigillaria brardii Brongniart, Prodrome, p. 65, 1828; Hist. d. Veg. Foss., p. 430, pl. 158, fig. 4, 1836.

Sigillaria spinulosa Germar, Verstein. v. Wettin u. Lobejun, p. 58, pl. 25, 1848.

Sigillaria denudata Goeppert, Perm. Flora, p. 200, pl. 34, fig. 11, 1864-'65.

Sigillaria obliqua Lesquereux (non Brong.), Coal Flora, p. 470, pl. 73, fig. 18, 1879-'80.

Tree forms dichotomously branched, non-costate. Foliar cicatrices of the smaller branches closely interlaced, forming

The surface of the pinnule is thickly covered with a glandular structure or short hairs. Midvein of the pinnule marked by a flat depression on the upper side, continuing quite or very close to the apex, not decurrent at the base, or with a very slight downward turn just at its union with the rachis. Lateral veins at an angle of 45 or 50 degrees, nearly straight or slightly arched, usually simple, 7 to 10 on each side of the pinnule.

More or less confusion in regard to the characterization of *P. arborescens* has existed for some time. Zeiller[285] after careful study accepts Schlotheim's differentiation of *P. cyathea* from *P. arborescens;* while Potonié from a study of material from the type locality of the two species unites the two as synonyms.[286] Zeiller holds that *P. cyathea* is separated from *P. arborescens* by pinnules more nearly flat, narrower in proportion to their length, often unequal, veins often forked. Potonié, on the other hand, believes that the large pinnules with forked veins are merely the large pinnules of the large fronds of *P. arborescens.* This species is abundant in the Upper Coal Measures of Kansas, and is present in the Permian. The Kansas museum contains a good representation of the species from the Coal Measures. It has seemed to me from a study of this material that the *P. arborescens* and *P. cyathea* are distinct. The two pinnules of figure 5, plate XLV, are taken from near the base of a pinna about 40 cm. long. They should therefore be among the largest pinnules of the frond. In these pinnules the veins are always simple.

Formation and locality: This species is found in abundance from the Chanute shales through to the Wellington formation.

Pecopteris cyathea (Schlotheim) Brongn.

Felicites cyatheus Schlotheim, Peterfactenkunde, p. 403, 1820.

Pecopteris cyathea (Schloth.) Brongniart, Hist. Veget. Foss., pl. 10, figs. 1-4.

Pecopteris cyathea Schlotheim (sp.), Zeiller, Bassin d' Autun et d' Epinac, p. 43, pl. 8, figs. 2-4.

This species is very similar to *P. arborescens.* The pinnules appear to be more nearly flat, narrower in proportion to their length, often unequal in length, veins often forked.

Formation and locality: From the Scranton shales at Scran-

285. Bassin Houiller et Permien D'Autun et D'Epinac, p. 45, 1890.

286. Flora des Rothliegenden von Thuringen, p. 57, 1893.

This common and variable species occurs in the Cherokee shales and has been observed to extend as high as the Garrison formation at the top of the Upper Coal Measures. It is one of the abundant species throughout the series. The not inconsiderable change which the species undergoes during its long existence has led to its being recorded in earlier American literature under a variety of names, and has brought about much confusion in regard to its limiting characters. The common typical examples, with pinnules of medium size, have been commonly known as *Neuropteris loschii*, while the long, proportionally narrow, pinnules from the larger pinnæ are probably the same as those included by Lesquereux under the name *N. plicata*. Several large specimens in the University of Kansas collection from Thayer, Kan., indicate the immense size of the fronds. The large primary pinnæ has a strong, woody, flexuous rachis, with subopposite distant secondary pinnæ, between which are attached, directly to the rachis of the primary pinna, numerous ultimate pinnæ, 12 to 15 cm. long. The pinnules on this large frond are narrowly elongate, 18 to 25 mm. long, 8 to 10 mm. wide, the veins counting 35 to 40 per centimeter. Other specimens show that the secondary pinnæ were large, probably not less than a meter in length, the entire frond being no doubt several meters long. The specimens from the higher horizons show constantly broadly oblong or ovate pinnules, often distantly separated, with a flat, thin, flexuous rachis bending to meet the attachment of each pinnule. This later development of the species should perhaps receive a varietal name as marking a phase of the species found in high Coal Measures deposits.

Formation and locality: Cherokee shales, Lansing; Chanute shales, Thayer; Le Roy and Lawrence shales, and the Scranton shales, Scranton; Wabaunsee formation, Emporia; Chase formation at Washington.

Neuropteris hastata D. W. Pl. XLVIII, fig. 6; pl. XLIX, fig. 5.
Bull. No. 211, U. S. G. S., p. 97.

Fronds probably large; ranchises occurring with and probably belonging to the species 3 cm. wide, marked with many rather fine longitudinal striæ. Ultimate pinnæ linear, at right angles. Rachis slender, striate. Pinnules alternate, large, 3 to 5 cm. long, 1 to 2¼ mm. wide at the widest part, unequilateral, lower side much the larger, unsymmetrical in shape, broadest a little above the middle, then contracted rapidly to

of the frond very thin and shining. Nervation distinct. Midrib of the pinnules rather prominent, flexuous, decurrent at the base, marked by a thin line above, and by a thicker ridge below. Lateral veins distinct, distant, appearing as a ridge on both the upper and under side of the thin lamina.

This species is referred to the genus *Oligocarpia,* because of the close similarity of the sterile fronds in both the arrangement and the venation of the pinnules to the fronds of other species of that genus. The punctæ of the rachis, which become on the larger rachises thorn-like projections ½ mm. long and obtuse on top, separate the species from other species of *Oligocarpia.* These punctæ are placed irregularly on the rachis, varying from ½ to 3 or 4 mm. apart. From *Oligocarpia missouriensis* D. W. (Flora of the Lower Coal Measures of Missouri, p. 66, pl. 20, figs. 1, 2; pl. 21, figs. 1?, 2?, 3, 4) it differs further in that the veins are forked at a wider angle, and are perhaps more flexuous and curve more in passing to the border. From *Oligocarpia alabamensis* Lx. (Coal Flora, p. 266, pl. 47, figs. 1, 1*b*) it also differs by the strongly decurrent midrib of the pinnule, the tertiary and ultimate pinnæ having a much more distinct terminal pinnule. Along with the normal forms of the species occur several fragments having pinnæ small, lobate, and much narrower than those of the typical specimens. The fragments appear to represent a slightly different form of the species, or possibly a variety. *Oligocarpia kansasensis* has, in the appearance of the small pinnæ and the spiny rachis, some resemblance to *Sphenopteris mixta* Schimp., but Schimper's species is throughout more delicate, the rachises more slender, the lobes of the small pinnæ (as seen on specimens of the species from Clinton, Mo., and mentioned in David White's treatment of the species) are separated by a narrow decurring sinus, while in *O. kansasensis* they are separated by an obtuse, non-decurring sinus. The pinnules of *Sphenopteris mixta* do not reach the size of those of *O. kansasensis* before becoming lobate; while the lamina of the Kansas species is clearer, and the venation more distinct. The veins fork at a wide angle and traverse the thin lamina in a flexuous path. The venation of the ovate pinnules of the smaller pinnæ is shown in figures 16-18, plate XLV. The sori are placed along the pinnule rather nearer the border than the midrib. The sori are large and appear to be situated on the

overlapping, contracted toward the apex and obtusely pointed. Pinnules alternate, open or oblique, distant or overlapping, flat or slightly arched at the borders, sessile, sometimes united at the top of the pinnæ, cordate at the base, occasionally attached by a portion of the base to the rachis in the upper part of the pinnæ, oblong, the borders parallel or gradually narrowed upward to the obtuse or rounded apex. Terminal pinnules larger, comparatively long, somewhat hastate, cuneate below, usually sublobate, contracted in the upper part, lanceolate, often slightly undulate, rounded at the tip. Midrib strong, appearing as a furrow on the upper side of the pinnule, raised beneath, passing nearly to the apex of the leaf. Secondary veins thick, often appearing double, sometimes in relief on both sides of the pinnules, springing at a narrow angle from the midrib, arched, forking two or three times into thick, distant veinlets; venation of the cyclopterid pinnules flabellate, coarse, often appearing double.

This species is represented by a large number of good specimens from the Cherokee shales at Lansing, Kan. The preservation is good, the venation usually distinct. The frond often has a green coloration, apparently the coloring chlorophyll of the leaf. The frond is dense, the pinnules very much crowded or rarely distinct. The species is easily recognizable by the distant thick veins, counting about 22 to 26 per centimeter in the large pinnules, rather fewer in the smaller. The oblong-linear pinnules of the large pinnæ, such as the one shown in figure 5, plate XLVIII, are often constricted into small ovate lobes. In the specimens at hand the lobes appear, in every case, first on the upper side of the pinnule, just above the base, the lower side less deeply or only faintly lobed. The terminal pinnules of the Lansing specimens are in many cases more obtuse than those of the specimens figured by Lesquereux in the Coal Flora atlas. Lesquereux (Coal Flora, p. 111) mentions the presence of this species from a "shaft near Ellsworth, Kan." It is very probable that Leavenworth is the locality meant, the mine being the same as that from which came the specimens in the University collection. Ellsworth, in Ellsworth county, is in the Cretaceous area of Kansas. One large specimen shows the dichotomous character of the rachis.

Formation and locality: Cherokee shales, Lansing.

The species is represented by a great number of fragments from University Hill, preserved in a clayey shale, in which the venation seldom shows. The few pinnules in which the venation is preserved show the veins to be rather distant, thin, oblique, forked once in the small pinnules, perhaps simple in the very smallest, the upper vein forking again in the large pinnules, always at a wide angle; the first dichotomy close to the midrib, never more than one-third of the distance to the border. The fructification on these fragments from University Hill is too indefinite to figure, appearing only as roughened punctate-like dots covering the surface of the fertile pinules. The Twinmound concretions have some fructified specimens very well preserved, from which figure 14, plate XLV, is taken. The sori in these are seen to be placed irregularly over the surface, but with some approximation to two rows on each side of the midrib. The sori are nearly square and seem to be distinctly divided off into four compartments. The specimens are from University Hill, except the figured specimen from Twinmound.

Formation and locality: From the Lawrence shales, at Lawrence and Twinmound.

Aphlebia PRESL.

Aphlebia pinnules are numerous in the collections. A few of the more unusual are illustrated. The pinnule of figure 9, plate LVI, is found at Twinmound. A hirsute *Aphlebia* with short lobes, found at the Haverkampf farm in the Le Roy shales, is shown in figure 3, plate LV.

Spiropteris SCHIMPER.

The coiled apices of young fern fronds such as are usually referred to in fossil botany literature as *Spiropteris* occur not infrequently in the collections from both the Coal Measures and Permian formations.

Neuropteris BRONGNIART.

Mem. Mus. Hist. Nat., vol. 8, p. 333, 1822.

Neuropteris gilmani sp. nov. Pl. LVIII, fig. 4.

Pinnules very large, 4½ cm. broad, 11 mm. long, irregular in shape, ovate acuminate, sessile, base inequilateral, strongly auricled, having a large, nearly square lobe below, borders at first nearly parallel then sloping to an acuminate apex, irregularly undulate. Veins fine and numerous, about 45 per centi-

meter, many times dichotomous, spreading from the base without a midrib.

The absence of a distinct midrib, even in the very large pinnules, the pointed apex, and the large square base, are prominent characters of this species. The pinnules resemble in shape the pinnules of *N. clarksoni* and of the pointed variety of *N. scheuchzeri*. The venation is much like that of *N. scheuchzeri*, being very fine, numerous and equally close in all parts of the pinnule. The species is distinguished from *N. clarksoni* by the much more numerous veins, and from *N. scheuchzeri* by the square auricled base and the absence of basal leaflets. *N. anomala* is separated by its truncate base and fewer veins. *N. decipiens*, the only related species approaching this one in size, has very obtuse pinnules and fewer veins, counting only 24 to 30 per centimeter.

Formation and locality: Cherokee shales, Lansing, Kan. The type specimen was collected by Mr. J. M. Gilman, for whom the species is named.

Neuropteris clarksoni Lx.

Boston Soc. Nat. Hist., vol. 6, p. 417, 1854; Geol. of Penn., vol. 2, pt. 2, p. 857, pl. 6, figs. 1-4, 1858; Geol. Report, Illinois, vol. 2, p. 428, 1866; Coal Flora, vol. 1, p. 94, pl. 9, figs. 1-6, 1880.

Schimper, Traite Paleont. Veg., vol. 1, p. 446, 1869.

David White, Flora of Southwestern Missouri, Bull. U. S. G. S. No. 98, p. 79, 1893.

Fronds large. Primary rachis strong, dichotomous. Pinnules opposite or subopposite, open or slightly inclined, often more or less falcate, sloping to a pointed apex, largest and cordate at the base, lower side usually enlarged, attached by a strong pedicel, borders usually entire, often undulate. Midvein rather strong at the base, striate, soon reduced and passing to or near the apex as a thin line. Lateral veins given off at an acute angle, curving at first but slightly, then more decidedly, thin, counting about 25 to 30 per centimeter.

A few specimens have been found at Lansing, Kan., which seem to have the essential characters of *N. clarksoni*. The pinnules resemble in shape the acuminate variety of *N. scheuchzeri* found at the same locality, but are easily distinguished from that species by the more distant nervation and the absence of basal lobes. The nerves of the Lansing specimens count 29, 30, and 31 per centimeter. The midvein is stronger than that of *N. scheuchzeri*, is distinctly striated, and can be

seen to pass as a thin line almost to the apex. The base as seen on one of the pinnules is deeply cordate, attached by a strong short pedicel, the lower side of the base being enlarged and extending downward. The pinnules are subopposite, falcate or nearly straight, and are gradually narrowed to the pointed apex. The rachis to which the pinnules are attached is finely striate.

Formation and locality: Cherokee shales, Lansing, Kan.

Neuropteris vermicularis Lx. Pl. XLVIII, figs. 2, 3; pl. LVI, fig. 8. Geol. Rept. of Kentucky, vol. 4, p. 434, 1861; Geol. Rept. of Illinois, vol. 2, p. 428, 1866; ibid., vol. 4, p. 385, pl. 6, figs. 1-3, 1870; Schimper, Paleont. Veget., vol. 3, p. 474, 1869.

Pinnæ broadly linear or narrowly triangular, sloping from the base or a little above the base to an obtuse apex. Pinnules large, at right angles or inclined a little, alternate or subopposite, close or a little distant, usually very crowded, dense and overlapping, oblong, sides nearly parallel, apex obtusely rounded, base truncate, attached by the midvein, rounded a little above the base, the lower corners projecting downward, 1 to 4 or more cm. long, reduced toward the top, the last one partly connate with the broadly spatulate, lightly lobed terminal pinnule. Veins numerous but clear and distinct, midvein continuing to somewhat above the middle, lateral veins distant near the center of the pinnule, where they leave the midrib obliquely and curve gradually to the border, dichotomizing in the smaller pinnules two, three, or four times and counting 22 to 26 per centimeter, in the larger pinnules forking four to six times and counting 34 to 42 per centimeter. Lamina clear, the veins appearing as fine round threads.

The pinnules of this species present, as compared with most other ferns, an unusual range of variation in the number of veins per centimeter. The veins counted at the border become more numerous as the pinnule increases in size. In the small lateral pinnules having veins dichotomizing only two or three times the veins count at the border not more than 22 to 26 per centimeter. In the large pinnules, in which the divisions dichotomize four to six times the veins count 34 to 42 per centimeter, becoming in the largest pinnules as many as 44 per centimeter. Near the midrib the veins are distantly separated, becoming close at the border by numerous dichotomies, the number of dichotomies depending on the size of

broad angle, are more or less zigzag in their course, curve strongly, and meet the border at an oblique angle.

Formation and locality: Le Roy and Lawrence shales, Lawrence and Twinmound.

Neuropteris lindahli D. W. Pl. XLVIII, figs. 7, 8.
Bull. No. 211, U. S. G. S., p. 96, 1903.

This species differs from *N. elrodi* Lesqx. in that the rachis is distinctly striated and the terminal pinnule has a cordate base similar to that of the lateral pinnules. The pinnules are sometimes very close and overlapping.

Formation and locality: From near the base of the Bethany Falls limestone, Kansas City, Kan.

Linopteris PRESL.

Linopteris Presl. in Sternberg; Versuch, vol. 2, facl. 7-8, p. 167.

Linopteris obliqua (Bunb.) Pot. Pl. XLVIII, fig. 10.
Dictyopteris obliqua Bunbary, Carb. Form. of Cape Breton, Quart. Journ. Geol. Soc., vol. 3, p. 427, pl. 22, fig. 2.

This species seems to be rare at Lansing. Mr. Gilman has, however, obtained a few specimens which appear to be typical of the species.

Odontopteris BRONGNIART.

Felicites sect. *Odontopteris* Brongniart, Mem. Mus. Hist. Nat., vol. 8.

Odontopteris genuina Grand 'Eury. Pl. XLIX, figs. 1, 6.

Fronds bipinnate or more. Ultimate pinnæ subopposite, open or slightly oblique, close, lanceolate, terminated by an elongate-lanceolate pinnule. Rachis striate. Pinnules alternate, close, sessile by the entire base, oblique or open, oblong-ovate, obtusely rounded, sometimes contracted a little below the middle, smaller ones slightly united at the base, larger almost or quite free. Basal pinnules fan-shaped, ovate, deflexed; pinnules gradually passing into and becoming connate with a lanceolate or elongate obtuse terminal pinnule. Venation distinct. Veins very numerous, 36 to 40 per centimeter at the border. Median vein little developed in the small pinnules; in the large pinnules, however, a fascicle is traceable half the length of the pinnule; branches numerous, fine, forked from two to five times, last division often close to the border. Rachial veins numerous and arising directly from the rachis, except in the case of the large pinnules, which have the median fascicle developed to some extent.

The Kansas plant seems to agree with specimens from the Commentry deposits of France which I have seen in the Na-

tional Museum labeled by Monsieur Zeiller. The species is much like some specimens of *O. lingulata*, figured in European literature, but is distinguished from that species by a more strongly developed median fascicle of veins in the large pinnules and by the greater number of dichotomies of the veins, the last being closer to the border.

Formation and locality: Le Roy shales, Haverkampf farm.

Odontopteris anomada sp. nov. Pl. XLVI, figs. 6, 7; pl. LVI, fig. 4.
Neuropteris carrii Lesqx. prs. (?), Coal Flora, vol. 3, p. 733, pl. 94, figs. 5, 5*a*, 1884.

Pinnules large, of various shapes, anomalous, ovate-oblong or elongate, sessile by the base, often decurrent, open or curving back, borders entire or obtusely lobed, bordered or scalloped, or divided by acute sinuses into triangular pointed lobes. Veins very numerous, many times branched, sinuous, close when near the border, often uniting for some distance, then separating again. Rachial veins numerous. Midvein of the large, long pinnules moderately strong, branching some distance above the middle, giving off numerous branches which curve and meet the border at right angles, forking four or five times, becoming near the border very sinuous, often running into each other, and remaining contiguous for a greater or less distance.

Many specimens of this anomalous type have been obtained from the Haverkampf farm near Lawrence. There is seemingly no regularity of size or shape to the pinnules. A form in which the pinnule is unsymmetrical, its borders acutely lobed, is quite common. Others are ovate or ovate-oblong, with borders entire. The number of veins, the angle at which they fork, and especially the last dichotomy close to the border, suggest the associated plants which I have referred to *O. genuina*. The fossil plant collection of the Yale Museum contains a few pinnules from Mazon Creek which seem to be referable to this species, the shape of the pinnule and character of the venation being very much the same. The Mazon Creek plant in turn is very similar to some of the pinnules from that locality referred by Lesquereux to *N. carrii*.

Formation and locality: Le Roy shales, Haverkampf farm.

scriptions given by Lesquereux and White, I have no hesitancy in referring it to *N. missouriensis*. The epidermis of the ovate pinnules is dense, the veins not very distinct. The border on most of the pinnules appears a little thickened; the base is not quite equally rounded, the lower side being slightly produced downward. The pinnules are sessile by a thick midrib which in the specimen at hand can barely be traced to the middle of the pinnule. The pinnules are perhaps a little more distant than is usual for the species, being almost or quite free from each other.

Formation and locality: Cherokee shales, Lansing.

Neuropteris ovata Hoffman. Pl. XLVIII, fig. 9; pl. L, fig. 11; pl. LIII, fig. 2; pl. LVI, fig. 6.

Fronds very large, tri- or quadripinnate, dichotomous below. Primary pinnæ large, having a spread of 1 meter or more, length not known; rachis flexuous, woody, 2 cm. or more wide longitudinally, roughly striated, branching in a semidichotomous manner, and bending somewhat after giving off each of the strong secondary pinnæ. Ultimate pinnæ attached to the rachis, 3 to 5 cm. apart; five or six between each two secondary pinnæ. Secondary pinnæ subopposite or alternate, distant, not touching, or possibly overlapping at the middle, 20 to 25 cm. apart, at right angles, or inclined a little, narrowly ovate or approaching a linear form, contracted at the base by the shortening of the ultimate pinnæ, more pronounced on the upper side, narrowed at the apex, where the ultimate pinnæ pass into linear pinnules, one or two of which are more or less connate with the inequilateral terminal pinnule, 20 to 30 cm. wide at the widest part a little below the middle; rachis strong, roughly striate, as much as 12 mm. wide at the base. Ultimate pinnæ rather distant, 1½ to 4 cm., free or overlapping at the base, alternate or subopposite, inclined slightly, or at about right angles, or even reflexed near the base of the large pinnæ, sessile, broadly linear, sides nearly parallel, or sloping a little to an obtusely lanceolate apex, the last one or two pinnules partly connate with the large inequilateral terminal pinnule. Ultimate pinnæ replaced above by linear oblong pinnules which pass into the inequilateral terminal pinnule of the secondary pinna. Rachis moderately strong, straight, but sometimes, especially in the Upper Carboniferous forms, thin, flexuous, bending to meet the attachment of each of the distantly separated pinnules. Maximum length of the ultimate pinnæ, 10 to 15

more commonly about the middle. The pinnules are enlarged more or less at or above the middle, decurrent to the next pinnule below by a broad auricle, and cut in above the base by an acute sinus. The midrib is represented by a very thin line. Numerous glandular dots are seen between the veins, doubtless representing a mineral deposit.

Formation and locality: Cherokee shales, Lansing.

Alethopteris serlii var. missouriensis D. W. Pl. LVI, fig. 7.

Flora of the Lower Coal Measures of Missouri, p. 118, pl. 37, fig. 1-2; pl. 42, fig. 5.

The form with long narrow pinnules described from the Cherokee shales of Missouri under the above varietal name is found also at Lansing. It differs from the species in the more narrow pinnules, hardly at all enlarged above the base, and in that the acute sinus above the base is almost or entirely lacking.

Formation and locality: Cherokee shales, Lansing.

Alethopteris grandini (Brongn.) Goep. Pl. XLIX, figs. 3, 4; pl. LI, fig. 1; pl. LV, fig. 1; pl. LX, fig. 2.

Pecopteris grandini Brongniart, Hist. Veget. Foss. 1, p. 268, pl. 91, figs. 1-5; Heer, Fl. Foss. Helvet., p. 33, pl. 12, fig. 10*a*.

Alethopteris grandini, Goeppert Syst. Fil. Foss., p. 299; Renaul, Cours Bot. Foss., 3, pp. 157-159, pl. 27, figs. 3, 4, 13; Zeiller, Fl. Foss. Bass. Houill. de Valenciennes, p. 237, pl. 38, figs. 1, 2; Fl. Foss. Terr. Houill. de Commentry, 1st part, p. 203, pl. 21, figs. 1-8.

Pecopteris serlii Heer (non Brongniart), Fl. Foss. Helvet., p. 32, pl. 12, fig. 8.

Daneites emersoni Lesquereux, Coal Flora, p. 157, pl. 28, figs. 1-3.

Fronds very large, tripinnate or possibly quadripinnate at the base. Rachis strong, finely longitudinally striate. Primary pinnæ open, contracted to a pointed apex at the summit. Secondary pinnæ very deciduous, rather open, contiguous, linear-lanceolate, obtusely pointed at the summit, 7 to 20 cm. long, 12 to 40 mm. broad. The primary pinnæ are replaced above by simple pinnæ, the larger of which are pinnatifid, the smaller with undulate or entire borders. Pinnules open, inclined, straight or slightly arched backwards, decurrent, more or less connate at the base, separated by an obtuse sinus, borders almost parallel, sometimes slightly enlarged at the middle, rounded at the apex, 6 to 25 mm. long, 4 to 10 broad; terminal pinnule short, oval or linear. Median vein distinct, continuing quite to the summit; secondary veins attached at an

angle of 45 to 60 degrees, lower veins arising directly from the rachis.

The larger pinnæ of this species reach a length of 20 cm. The pinnules of these large pinnæ are but slightly or not at all connate at the base. Near the tip of the pinna the pinnules become connate and decurrent at the base. The pinnules are irregular in size, shape and inclination to the rachis. As a rule, the basal pinnules are deflexed. The midvein is strong and continues to near the apex, where it terminates suddenly. The lateral veins fork once near the midvein. Occasionally they are simple.

Formation and locality: This species is abundant in the Le Roy shales, and has been obtained from the Scranton shales at Scranton. Mr. White (Bull. U. S. Geol. Survey No. 211, p. 112) records its presence at Thayer.

Callipteridium WEISS.

Callipteridium sullivantii Lx. Pl. L, figs. 1, 2; pl. LX, fig. 1.

Callipteridium sullivantii Lesquereux, Bost. Soc. Nat. Hist., vol. 6, No. 4, p. 423, 1854.

This species is present in typical form at Lansing in the Cherokee shales. The large pinnæ have pinnules irregular in size and shape, some being broad and short while others are more slender and longer.

Formation and locality: Cherokee shales, Lansing.

Callipteridium sp. Pl. XLV, fig. 22.

An undetermined species of *Callipteridium* occurs at the Haverkampf locality in the Le Roy shales. The pinnules are found occasionally in the concretions from that locality.

LYCOPODIALES.

SIGILLARIACEÆ.

Sigillaria BRONGNIART.

Mem. Mus. Hist. Nat., vol. 8, p. 209, 1822.

Sigillaria brardii Brong. Pl. LI, fig. 8; pl. LVII, figs. 1, 3.

Sigillaria brardii Brongniart, Prodrome, p. 65, 1828; Hist. d. Veg. Foss., p. 430, pl. 158, fig. 4, 1836.

Sigillaria spinulosa Germar, Verstein. v. Wettin u. Lobejun, p. 58, pl. 25, 1848.

Sigillaria denudata Goeppert, Perm. Flora, p. 200, pl. 34, fig. 11, 1864-'65.

Sigillaria obliqua Lesquereux (non Brong.), Coal Flora, p. 470, pl. 73, fig. 18, 1879-'80.

Tree forms dichotomously branched, non-costate. Foliar cicatrices of the smaller branches closely interlaced, forming

a cancellate network, somewhat hexagonal, transverse width about twice the vertical, acutely angled at the sides, rounded above and below, projecting from the surface slightly, varying in size according to position whether close to or distant from the regular enlargements of the branch, and according to the size of the branch, on the large branches becoming indistinct or absent. Leaf-scar angled at the sides, rounded below, always more or less emarginate above, inclined upward, facing upward and outward, the upper edge dipped slightly under the next foliar cicatrice above, the lower side projecting a little over the one below, varying in size according to the position on the branch and the size of the branch, from very small, 2 mm. in longitudinal width to 7 or 8 mm., separated in the spiral and transverse direction from 1 or 2 mm. to 2 or more cm.; the central cicatricule located above the middle of the scar, elevated, transversely broadly linear; lateral cicatricules just at the side of the vascular point nearly straight and linear in the vertical direction, or curved, enclosing the vascular point as in parentheses. Cortex thin, marked on the large branches by more or less undulating longitudinal striæ; lateral cicatricules of the decorticated surface small, linear, parallel in a vertical direction. Vascular point on well-preserved specimens showing as a point midway between the cicatricules, decorticated surface striated. Continuity of the branch interrupted by regularly occurring enlargements, the distance between which becomes gradually less approaching the apex; fructifications probably borne on cones attached to these enlargements.

Formation and locality: Le Roy, Lawrence and Scranton shales.

Sigillaria brardii coriacea D. W.

The variety which Mr. David White has separated under the varietal name *coriacea* occurs rather abundantly in the Le Roy shales at the coal-mines formerly operated at Blue Mound.

Sigillaria camptotænia Wood.

The widely distributed species *S. camptotænia* has been identified from the Le Roy shales at Blue Mound, near Lawrence, and is reported by White from the Chanute shales (Bull. U. S. Geol. Survey No. 211).

Sigillaria sp. Pl. LI, fig. 2.

Trees large; cortical surface finely rugose longitudinally; cortex thin, marked on the shale by a thin carbonaceous layer

not more than ¼ mm. thick; bolsters absent; leaf-scar projecting not at all from the cortex, marked by a thin line; scars truncate at the top, obtusely rounded at the base, acuminate-pointed at the sides, more than a third wider than long. Scars on the specimen at hand 15 mm. transversely, 8 or 9 vertically, spirally and vertically equidistant 37 mm.; central vascular scars transversely elongated. Lateral cicatricules very prominent, large elongate-ovate marks. The subcorticated surface is distinctly longitudinally striate. The surface of the lateral cicatricules is thickly set with punctæ. The decorticated surface is deeply marked by the elongate-ovate lateral cicatricules.

Formation and locality: Le Roy shales, Blue Mound.

Sgillaria sp.

Trees large, bark thick and rough, apparently ribbed longitudinally, striate and rugose scars approximately vertically and transversely equidistant. Lateral cicatricules unusually large, distant, elongate-ovate, dotted with punctæ and resembling those of the species just described, from which the species differs, however, in that the cortex is very thick and rough. The lateral cicatricules in the largest specimens are 5 to 6 mm. distant.

Formation and locality: Le Roy shales, Blue Mound.

Leaves of Sigillariaceæ. Pl. XLVII, figs. 3-6, 9.

Comparatively few leaves of the *Sigillariaceæ* have been figured or described. White gives a good description of the leaves of *Sigillaria* found in the Carboniferous basins of southwestern Missouri.[289] Lesquereux figures (Geol. Surv. Ill., vol. 2, pl. 45, figs. 6 and 7) two fragments of leaves which may be of this genus. Illustrations of a number of specimens will be found also in monograph 37 of the United States Geological Survey. In connection with the description of a specimen of *Sigillaria monistigma* from Lawrence, Kan., Lesquereux mentions leaves 3 mm. broad, with a median keel and two lateral "veinlets," which are stated to be still attached to the stem.[290] There is a remarkable uniformity in the leaves of the *Sigillariaceæ* considering the number of species as indicated by variations in the trunks of the trees. The characters which seem to be common to the leaves of the *Sigillariaceæ* may be summarized as follows: Leaves long, slender, very narrow in proportion to

289. Bull. U. S. Geol. Surv. No. 98, p. 103.

290. Coal Flora, vol. 3, p. 793.

their length, uninerved, pointed at the apex, enlarged and thickened at the base, a strong median keel at the center, lateral traces (parichnos) well marked.

LEPIDODENDRACEÆ.

Lepidodendron STERNBERG.

Lepidodendron scutatum Lx. Pl. LVI, fig. 3.

Lepidodrendon scutatum Lesquereux, Coal Flora, p. 269, pl. 63, figs. 6, 6*b*, 6*c*; David White, Flora of the Lower Coal Measures of Missouri, p. 198, pl. 45, fig. 4; pl. 54, fig. 5; pl. 55, figs. 1, 2; pl. 72, fig. 4, 1899.

This species seems to be represented by a single specimen of a small dichotomous branch from Lansing, Kan. The stem is slender, only 5 mm. wide below the dichotomy, the bolsters elliptical or broadly elliptical, 2½ to 3 mm. long, about one-third as wide as long, acute above and below, rounded at the sides. The leaf-scar is placed above the middle.

Lepidodendron clypeatum (?) Lx. Pl. LI, fig. 5.

A specimen referred doubtfully to *L. clypeatum* occurs in the collection from the Cherokee shales at Lansing.

Lepidocystis Lx.

Lepidocystis Lesquereux, Coal Flora, p. 454, 1880.
Sporocystis Lesquereux, Coal Flora, p. 458, 1880..

Lepidocystis sp.

Spore-cases arranged spirally on a slender axis, oblong, one-half to one-third as wide as long, sessile, obtuse at both ends, close, overlapping each other, sessile without evidence of subtending bracts; spore-case covering numerous thin macrospores, rounded on one side, triradiate on the other.

The spore-cases described here are of the proportions and general appearance of the three isolated spore-cases figured by Lesquereux (*loc. cit.*) and referred to the genus *Sporocystis*, but without specific name. Their attachment in a spiral manner to an axis brings them within the genus *Lepidocystis*, as originally characterized. It has been suggested on the evidence of association that the spore-cases belong to the large-leaved *Lepidophyllum*, and these are in turn referred by Goldenberg and White to trunks described under the name *Lepidophloios*.

Formation and locality: Cherokee shales, Lansing.

Neuropteris scheuchzeri Hoffm. Pl. XLVI, fig. 8.

Neuropteris scheuchzeri Hoffman, in Kieferstein, vol. 4, p. 157, pl. 1*b*, figs. 1-4, 1826.

Neuropteris hirsuta Lesquereux, Boston Journal Science Nat. Hist., vol. 6, p. 417, 1854.

Neuropteris fasciculata Lesquereux (pars.), Geol. Report, Illinois, vol. 4, p. 381.

Neuropteris scheuchzeri in its varying forms is present in the Kansas Coal Measures from the Cherokee shales to the Garrison formation. The specimens from Lansing, 100 feet below the top of the Cherokee shales, are for the most part narrow, more or less distinctly pointed at the apex, in which respect they approach the form found at Clinton, Mo., and for which White has suggested the varietal name *angustifolia.* A few much larger pinnules occur at this locality, approaching in size *Neuropteris discipiens,* from which they are, however, separated by their finer nervation. The species is exceedingly abundant in the Le Roy and Scranton shales.

N. scheuchzeri differs from its nearest relative, *N. decipiens* Lesqx., by its more numerous veins, counting 35 to 45 and even 50 per centimeter, while *N. decipiens* has an average of 26 to 32 per centimeter; rarely as few as 22 or as many as 35. *N. decipiens* has also a much larger and more obtuse pinnule with stronger hairs. The constancy of these characters on many hundreds of specimens from the type locality of *N. decipiens* which I have examined appear to me sufficient reason for retaining, as White suggests, the two forms separate. Under the name *N. fasciculata* Lesquereux has apparently described and figured anomalous or cyclopterid pinnules of more than one species. As for the Mazon Creek representatives of *N. fasciculata* the several specimens that have come to my notice have presented quite uniformly the distinctive characters of *N. decipiens.* Other figured specimens appear to belong, in part at least, to *Neuropteris scheuchzeri.*

Mr. David White has given a careful description and full discussion of this species in Bulletin 98 of the United States Geological Survey, to which the reader is referred for a more detailed account. The terminal pinnule of the secondary pinna is peculiar. It is easily recognized by its elliptical shape, symmetrical and slightly cordate base attached to a pedicel-like extension of the rachis. These terminal pinnules are not infrequently found detached. Below the terminal pinnule is found one or more pairs of lateral pinnules, slightly petiolate,

cordate, inequilateral, the lower side of the base being extended, separated by a distance of 5 or more mm. from the terminal pinnule. These lateral pinnules are succeeded below by the normal trifoliate pinnæ of the species. Several specimens from the Le Roy shales have one pair only of small simple pinnules before passing to the trifoliate pinnæ.

Formation and locality: From the Cherokee shales to the Chase formation.

Neuropteris desorii Lx.[288] Pl. XLVIII, fig. 11; pl. L, figs. 7-10; pl. LIV, fig. 1.

Ultimate pinnæ linear, taper-pointed, compact, sloping gradually and regularly from near the base to the slender, obtusely rounded apex. Rachis slender, striate, marked by a depressed channel above, rounded and projecting below. Pinnules close, oblique, or becoming very open at the base of the pinna, sessile by the entire base, or the larger ones rounded slightly at the rachis, oblong, or ovate-oblong, apex very obtusely rounded, largest reaching a size of 14 mm. long, 6 wide, broadest at the base, reduced gradually but slightly to the rounded apex, or reduced more decidedly to somewhat pointed apex, slightly decurrent, touching, usually slightly connate with the pinnule below, reduced toward the apex of the pinna, becoming more distinctly connate, broader in proportion to their length, the obliquely inclined lobes at last passing into the faintly lobate, lanceolate, obtusely pointed terminal pinnule. Venation distinct. The midvein of the larger pinnules is slightly decurrent at the base, enters the pinnule at or below the middle, and is traceable one-half the length of the pinnule. The lateral veins curve more or less in passing to the border, which they meet at an oblique, or sometimes somewhat acute, angle, forked two or three times at a rather broad angle, more or less flexuous in the lamina, 18 to 26 per centimeter. A few veins, two to four, from the rachis, supply the decurring base of the pinnule. In the smaller pinnules the midvein becomes less conspicuous. The several veins supplying the lobes arise from a scarcely thickened vein, curving down, and running for some distance nearly parallel to the rachis before uniting; lamina rather thick.

This clearly marked species is abundant in the Lawrence shales. The normal shape and venation is shown in figures 7 to 10, plate L, in which the numerous veins fork at a rather

288. *Neuropteris desorii* Lesquereux, Journ. Bost. Soc. Nat. Hist., vol. 6, p. 418, 1854.

Odontopteris excelsa sp. n. Pl. XLIX, figs. 7-9.

Fronds large, bipinnate or more. Ultimate pinnæ long, linear or linear-lanceolate, reduced at the top of the frond, passing gradually into pinnatifid and simple pinnules. Pinnules large, open or inclined forward, oblong-ovate, obtusely rounded, sessile, large ones free to the base; smaller ones connate, divided by an acute sinus; pinnules of the ultimate pinnæ passing into lobes of a large, obtusely pointed terminal pinnule. Texture thin. Veins distant, distinct, arising from four to five rather thick decurring basal facicles, of which the one supplying the apical part of the pinnule is the stronger and has several branches.

This characteristic species is closest perhaps to *O. lingulata* by the large terminal and broad lateral pinnules, but is distinguished by the fewer and more distant veins arising from four to six basal veins, while in *O. (obtusa) lingulata* numerous fine veins spring from the base.

The largest ultimate pinnæ preserved, 13 cm. long, is incomplete. The lower pinnules, such as shown in figure 7, plate XLIX, are very broadly ovate, squarish, free to the sessile base, slightly rounded at the apex. The smaller pinnules above are inclined forward a little, obtusely pointed. Another specimen shows the pointed penultimate pinnæ ending in a terminal pinnule.

Formation and locality: Le Roy and Lawrence shales at Lawrence, the Scranton shales at Osage City, and the Chase formation at Washington.

Odontopteris minor Brongn. Pl. XLV, fig. 21.

This species occurs rarely in the Le Roy shales at the Haverkampf farm. The specimens obtained have been for the most part fragments of pinnæ. The agreement with the European specimens of *O. minor* seem to be satisfactory. This species has been recognized also from the Wellington shales at Banner City.

Alethopteris Sternberg.

Alethopteris serlii (Brongn.) Goep. Pl. L, fig. 5.

Pecopteris serlii Brongniart, Prodrome, p. 57, 1828.

Alethopteris serlii (Brongn.) Goeppert, Systema Fil. Foss., p. 301, pl. 21, figs. 6, 7, 1836.

This species occurs at Lansing but is not very abundant. The lateral veins are thin, nearly straight or somewhat wavy, simple or forked once at irregular distances from the midrib,

more commonly about the middle. The pinnules are enlarged more or less at or above the middle, decurrent to the next pinnule below by a broad auricle, and cut in above the base by an acute sinus. The midrib is represented by a very thin line. Numerous glandular dots are seen between the veins, doubtless representing a mineral deposit.

Formation and locality: Cherokee shales, Lansing.

Alethopteris serlii var. missouriensis D. W. Pl. LVI, fig. 7.
Flora of the Lower Coal Measures of Missouri, p. 118, pl. 37, fig. 1-2; pl. 42, fig. 5.

The form with long narrow pinnules described from the Cherokee shales of Missouri under the above varietal name is found also at Lansing. It differs from the species in the more narrow pinnules, hardly at all enlarged above the base, and in that the acute sinus above the base is almost or entirely lacking.

Formation and locality: Cherokee shales, Lansing.

Alethopteris grandini (Brongn.) Goep. Pl. XLIX, figs. 3, 4; pl. LI, fig. 1; pl. LV, fig. 1; pl. LX, fig. 2.
Pecopteris grandini Brongniart, Hist. Veget. Foss. 1, p. 268, pl. 91, figs. 1-5; Heer, Fl. Foss. Helvet., p. 33, pl. 12, fig. 10*a*.
Alethopteris grandini, Goeppert Syst. Fil. Foss., p. 299; Renaul, Cours Bot. Foss., 3, pp. 157-159, pl. 27, figs. 3, 4, 13; Zeiller, Fl. Foss. Bass. Houill. de Valenciennes, p. 237, pl. 38, figs. 1, 2; Fl. Foss. Terr. Houill. de Commentry, 1st part, p. 203, pl. 21, figs. 1-8.
Pecopteris serlii Heer (non Brongniart), Fl. Foss. Helvet., p. 32, pl. 12, fig. 8.
Daneites emersoni Lesquereux, Coal Flora, p. 157, pl. 28, figs. 1-3.

Fronds very large, tripinnate or possibly quadripinnate at the base. Rachis strong, finely longitudinally striate. Primary pinnæ open, contracted to a pointed apex at the summit. Secondary pinnæ very deciduous, rather open, contiguous, linear-lanceolate, obtusely pointed at the summit, 7 to 20 cm. long, 12 to 40 mm. broad. The primary pinnæ are replaced above by simple pinnæ, the larger of which are pinnatifid, the smaller with undulate or entire borders. Pinnules open, inclined, straight or slightly arched backwards, decurrent, more or less connate at the base, separated by an obtuse sinus, borders almost parallel, sometimes slightly enlarged at the middle, rounded at the apex, 6 to 25 mm. long, 4 to 10 broad; terminal pinnule short, oval or linear. Median vein distinct, continuing quite to the summit; secondary veins attached at an

angle of 45 to 60 degrees, lower veins arising directly from the rachis.

The larger pinnæ of this species reach a length of 20 cm. The pinnules of these large pinnæ are but slightly or not at all connate at the base. Near the tip of the pinna the pinnules become connate and decurrent at the base. The pinnules are irregular in size, shape and inclination to the rachis. As a rule, the basal pinnules are deflexed. The midvein is strong and continues to near the apex, where it terminates suddenly. The lateral veins fork once near the midvein. Occasionally they are simple.

Formation and locality: This species is abundant in the Le Roy shales, and has been obtained from the Scranton shales at Scranton. Mr. White (Bull. U. S. Geol. Survey No. 211, p. 112) records its presence at Thayer.

Callipteridium WEISS.

Callipteridium sullivantii LX. Pl. L, figs. 1, 2; pl. LX, fig. 1.

Callipteridium sullivantii Lesquereux, Bost. Soc. Nat. Hist., vol. 6, No. 4, p. 423, 1854.

This species is present in typical form at Lansing in the Cherokee shales. The large pinnæ have pinnules irregular in size and shape, some being broad and short while others are more slender and longer.

Formation and locality: Cherokee shales, Lansing.

Callipteridium sp. Pl. XLV, fig. 22.

An undetermined species of *Callipteridium* occurs at the Haverkampf locality in the Le Roy shales. The pinnules are found occasionally in the concretions from that locality.

LYCOPODIALES.

SIGILLARIACEÆ.

Sigillaria BRONGNIART.

Mem. Mus. Hist. Nat., vol. 8, p. 209, 1822.

Sigillaria brardii Brong. Pl. LI, fig. 8; pl. LVII, figs. 1, 3.

Sigillaria brardii Brongniart, Prodrome, p. 65, 1828; Hist. d. Veg. Foss., p. 430, pl. 158, fig. 4, 1836.

Sigillaria spinulosa Germar, Verstein. v. Wettin u. Lobejun, p. 58, pl. 25, 1848.

Sigillaria denudata Goeppert, Perm. Flora, p. 200, pl. 34, fig. 11, 1864-'65.

Sigillaria obliqua Lesquereux (non Brong.), Coal Flora, p. 470, pl. 73, fig. 18, 1879-'80.

Tree forms dichotomously branched, non-costate. Foliar cicatrices of the smaller branches closely interlaced, forming

a cancellate network, somewhat hexagonal, transverse width about twice the vertical, acutely angled at the sides, rounded above and below, projecting from the surface slightly, varying in size according to position whether close to or distant from the regular enlargements of the branch, and according to the size of the branch, on the large branches becoming indistinct or absent. Leaf-scar angled at the sides, rounded below, always more or less emarginate above, inclined upward, facing upward and outward, the upper edge dipped slightly under the next foliar cicatrice above, the lower side projecting a little over the one below, varying in size according to the position on the branch and the size of the branch, from very small, 2 mm. in longitudinal width to 7 or 8 mm., separated in the spiral and transverse direction from 1 or 2 mm. to 2 or more cm.; the central cicatricule located above the middle of the scar, elevated, transversely broadly linear; lateral cicatricules just at the side of the vascular point nearly straight and linear in the vertical direction, or curved, enclosing the vascular point as in parentheses. Cortex thin, marked on the large branches by more or less undulating longitudinal striæ; lateral cicatricules of the decorticated surface small, linear, parallel in a vertical direction. Vascular point on well-preserved specimens showing as a point midway between the cicatricules, decorticated surface striated. Continuity of the branch interrupted by regularly occurring enlargements, the distance between which becomes gradually less approaching the apex; fructifications probably borne on cones attached to these enlargements.

Formation and locality: Le Roy, Lawrence and Scranton shales.

Sigillaria brardii coriacea D. W.

The variety which Mr. David White has separated under the varietal name *coriacea* occurs rather abundantly in the Le Roy shales at the coal-mines formerly operated at Blue Mound.

Sigillaria camptotænia Wood.

The widely distributed species *S. camptotænia* has been identified from the Le Roy shales at Blue Mound, near Lawrence, and is reported by White from the Chanute shales (Bull. U. S. Geol. Survey No. 211).

Sigillaria sp. Pl. LI, fig. 2.

Trees large; cortical surface finely rugose longitudinally; cortex thin, marked on the shale by a thin carbonaceous layer

not more than ¼ mm. thick; bolsters absent; leaf-scar projecting not at all from the cortex, marked by a thin line; scars truncate at the top, obtusely rounded at the base, acuminate-pointed at the sides, more than a third wider than long. Scars on the specimen at hand 15 mm. transversely, 8 or 9 vertically, spirally and vertically equidistant 37 mm.; central vascular scars transversely elongated. Lateral cicatricules very prominent, large elongate-ovate marks. The subcorticated surface is distinctly longitudinally striate. The surface of the lateral cicatricules is thickly set with punctæ. The decorticated surface is deeply marked by the elongate-ovate lateral cicatricules.

Formation and locality: Le Roy shales, Blue Mound.

Sgillaria sp.

Trees large, bark thick and rough, apparently ribbed longitudinally, striate and rugose scars approximately vertically and transversely equidistant. Lateral cicatricules unusually large, distant, elongate-ovate, dotted with punctæ and resembling those of the species just described, from which the species differs, however, in that the cortex is very thick and rough. The lateral cicatricules in the largest specimens are 5 to 6 mm. distant.

Formation and locality: Le Roy shales, Blue Mound.

Leaves of Sigillariaceæ. Pl. XLVII, figs. 3-6, 9.

Comparatively few leaves of the *Sigillariaceæ* have been figured or described. White gives a good description of the leaves of *Sigillaria* found in the Carboniferous basins of southwestern Missouri.[289] Lesquereux figures (Geol. Surv. Ill., vol. 2, pl. 45, figs. 6 and 7) two fragments of leaves which may be of this genus. Illustrations of a number of specimens will be found also in monograph 37 of the United States Geological Survey. In connection with the description of a specimen of *Sigillaria monistigma* from Lawrence, Kan., Lesquereux mentions leaves 3 mm. broad, with a median keel and two lateral "veinlets," which are stated to be still attached to the stem.[290] There is a remarkable uniformity in the leaves of the *Sigillariaceæ* considering the number of species as indicated by variations in the trunks of the trees. The characters which seem to be common to the leaves of the *Sigillariaceæ* may be summarized as follows: Leaves long, slender, very narrow in proportion to

289. Bull. U. S. Geol. Surv. No. 98, p. 103.

290. Coal Flora, vol. 3, p. 793.

their length, uninerved, pointed at the apex, enlarged and thickened at the base, a strong median keel at the center, lateral traces (parichnos) well marked.

LEPIDODENDRACEÆ.

Lepidodendron STERNBERG.

Lepidodendron scutatum Lx. Pl. LVI, fig. 3.

Lepidodrendon scutatum Lesquereux, Coal Flora, p. 269, pl. 63, figs. 6, 6*b*, 6*c*; David White, Flora of the Lower Coal Measures of Missouri, p. 198, pl. 45, fig. 4; pl. 54, fig. 5; pl. 55, figs. 1, 2; pl. 72, fig. 4, 1899.

This species seems to be represented by a single specimen of a small dichotomous branch from Lansing, Kan. The stem is slender, only 5 mm. wide below the dichotomy, the bolsters elliptical or broadly elliptical, 2½ to 3 mm. long, about one-third as wide as long, acute above and below, rounded at the sides. The leaf-scar is placed above the middle.

Lepidodendron clypeatum (?) Lx. Pl. LI, fig. 5.

A specimen referred doubtfully to *L. clypeatum* occurs in the collection from the Cherokee shales at Lansing.

Lepidocystis Lx.

Lepidocystis Lesquereux, Coal Flora, p. 454, 1880.
Sporocystis Lesquereux, Coal Flora, p. 458, 1880..

Lepidocystis sp.

Spore-cases arranged spirally on a slender axis, oblong, one-half to one-third as wide as long, sessile, obtuse at both ends, close, overlapping each other, sessile without evidence of subtending bracts; spore-case covering numerous thin macrospores, rounded on one side, triradiate on the other.

The spore-cases described here are of the proportions and general appearance of the three isolated spore-cases figured by Lesquereux (*loc. cit.*) and referred to the genus *Sporocystis*, but without specific name. Their attachment in a spiral manner to an axis brings them within the genus *Lepidocystis*, as originally characterized. It has been suggested on the evidence of association that the spore-cases belong to the large-leaved *Lepidophyllum*, and these are in turn referred by Goldenberg and White to trunks described under the name *Lepidophloios*.

Formation and locality: Cherokee shales, Lansing.

Sigillariastrobus.

Sigillariastrobus sp.

Sporangiophores obovate, close, 4 to 6 mm. long, 3 mm. wide, club-shaped, short pedicellate, largest at the upper end. Cone flattened by crushing. The sigillara cones of this type are numerous in the abandoned coal-mine at Blue Mound, in association with stems of *Sigillaria*. They reach a considerable length—as much as a foot or more. Not infrequently the macrospores are preserved in place.

Formation and locality: Le Roy shales at Blue Mound.

Sporangia, detached.

Two specimens from the Le Roy shales at Blue Mound show numerous clusters of sporangia detached and lying alongside a rachis. They were apparently attached to the rachis by a short pedicel. The sporangia are in clusters of fours, united at the base. They are about 1 mm. in length, the free ends being pointed. The cluster of sporangia is square in cross-section at the base. The rachis on which from their position they seem to have been borne, is slender, striated, and without attached leaflets.

EQUISETALES.

CALAMARIEÆ.

Calamites SUCKOW.

Calamites ramosus Artis.

This species is rather abundant in the Le Roy shales.

Calamites suckowii Brongn.

Formation and locality: Found at Lansing, and very abundant in the Le Roy shales; also present in the Scranton shales at Scranton.

Calamites cistii Brongn.

This species is not uncommon in the Le Roy shales at Lawrence.

Asterophyllites BRONGNIART.

Asterophyllites equisetiformis (Schloth.) Brongn.

Formation and locality: Found in the Cherokee shales at Lansing, Chanute shales at Thayer, and in the Le Roy, Lawrence and Scranton shales. The few specimens observed from Lansing are all of a less robust type than is common in the higher formations. The species has also been obtained by

White from the Elmdale shales at Onaga. (Bull U. S. Geol. Surv. No. 211.)

Annullaria STERNBERG.

Versuch einar Flora der Vorvelt, vol. 1, fascl. 2, p. 36, 1823.

Annullaria sphenophylloides (Zenk.) Gutb. Pl. LIII, fig. 5.

The normal form of this species is represented by several specimens from Lansing.

Annullaria sphenophylloides var. **intermedia.**

Lesquereux (Coal Flora, p. 724) established the variety *intermedia* for the large-leaved *Annullaria sphenophylloides* occurring in the Le Roy shales, for which the following diagnosis was given: "Branches much and horizontally divided; whorls of leaves measuring laterally or in the broadest side from 8 to 30 mm., composed of fourteen to twenty-two oblanceolate-obtuse, more or less inflated, leaflets; median nerve obscure." The variety is to some extent intermediate between *A. stellata* and *A. sphenophylloides,* having larger whorls than typical representatives of the latter, and broader, more obtuse leaflets than the former.

Formation and locality: Le Roy, Scranton and Emporia shales.

Annullaria stellata (Schloth.) Wood.

A. stellata is present in the Coal Measures from the Cherokee shales to the Garrison formation. The verticils from the Cherokee shales at Lansing have rather slender leaves, obtusely rounded at the apex and narrowed to a slender attachment at the base. The lamina is rough, somewhat scaly. Fine striæ are present in the lamina. The species is common in the Le Roy shales, the leaflets in some cases reaching a length of 4 cm.

Macrostachya SCHIMPER.

Traite Paleont. Veg., vol. 1, p. 333, 1869.

Macrostachya cf. infundibuliformis Schimper. Pl. LIII, fig. 6.

The spike which I refer provisionally to this species is not sufficiently well preserved to be positively determinable. The shape is much like that figured by Germar and referred to this species. The scales are acute at the top, the free tips being rather longer than the united bases. In general they resemble closely the scales figured by Lesquereux as belonging to this species. The spike is obtusely pointed at the top, narrowed a little toward the base, slightly curved. The articula-

Sigillariastrobus.

riastrobus sp.

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tions are close and the scales much overlapping. The scales are plainly uninerved.

Formation and locality: Cherokee shales, Lansing.

SPHENOPHYLLALES.

SPHENOPHYLLEÆ.

Sphenophyllum BRONGNIART.

Sphenophyllites Brongniart, Mem. Mus. Nat. Hist., vol. 8, p. 209, 1822.
Sphenophyllum Brongniart, Prodrome, p. 65, 1828.

Sphenophyllum cuneifolium (Sternb.) Zeiller. Pl. LIII, fig. 4.

Several specimens of this species have been obtained from Lansing. These have six slender leaflets to the verticil, slightly united or rarely free to the base, elongate, slightly broader at the apex than at the base. The apex is sharply toothed, and more or less distinctly cut down the middle. Two veins leave the base, one or both of which branch within 1 mm. of the base; the four veins then continue simple and enter the teeth. The leaflets are from 5 to 6 mm. long, about 2 mm. wide, and have three to six teeth. These specimens are very much like the *S. cuneifolium* found at Clinton, Mo. The species is abundant in the Chanute and Lawrence shales. The leaflets of these specimens are for the most part very narrowly cuneate, long, and almost always bifurcate. The specimen from Twinmound, photographed on plate LIII, figure 4, has close internodes, about 8 mm., verticils of six narrowly cuneate, bidentate, six- to eight-toothed leaflets; two veins leave the base and soon fork, one or both branches forking again about the middle of the leaflet. The surface is rough and dark, the veins thin. The leaflets are somewhat unequal, the lower ones being perhaps smaller, 6 to 7 mm. long, 3 to 3½ mm. wide, the lateral 7 to 9 mm. long, 3 to 4 broad. The lower leaflets, however, are bent back over the node, thus causing them to seem, perhaps, shorter than they really are. The internodes are marked by four or five strong ridges. The largest leaflets observed in the Lawrence shales are 12 mm. long, 3 to 4 wide, narrowed to a very slender point of attachment, and have about eight veins ending in as many teeth.

Formation and locality: Cherokee shales, Lansing; Chanute shales, Thayer; Le Roy and Lawrence shales, Lawrence.

Sphenophyllum emarginatum Brong. Pl. XLVII, figs. 7, 8.

Sphenophyllites emarginatus Brongniart, Class. Veget. Foss., p. 234, pl. 2, figs. 8, 8*a*, 8*b*, 1822.

Sphenophyllum emarginatum Brongniart, Prodrome, p. 68, 1828.

This species as developed in the Le Roy shales has leaflets 10 to 16 mm. long, 9 to 10 mm. wide at the apex. The sides are more or less concave and the apices obtusely rounded and lightly toothed. The veins count 12 to 16 to the leaflet and originate from two main veins at the base.

Formation and locality: Le Roy shales, Lawrence, Kan.

Sphenophyllum majus Bronn. Pl. LVII, fig. 4.

Rotularia major Bronn, in Bichoff: Kryptogam, Gewachse, vol. 2, p. 89, pl. 13, fig. 2*a-b*, 1828.

Sphenophyllum majus Bronn, Leth. Geog., vol. 1, p. 32, pl. 8, fig. 9*a-b*.

Sphenophyllum longifolium (Germ.), Lesquereux, Coal Flora, vol. 1, p. 53; vol. 3, p. 726, pl. 91, fig. 6.

Stem distinctly ribbed; internodes 2 to 3 cm. Verticils often overlapping, of six (rarely more) wedge-shaped leaflets, lateral margins straight, free at the base, distal border truncate or slightly rounded. Leaflets 12 to 28 mm. long, 8 to 15 mm. wide at the apex, narrowed to a slender free base. Leaflets toothed, often more or less deeply bifid. Nerves distinct, arising from two basal nerves, spreading and dichotomizing, becoming 12 to 24, ending in the teeth.

White has restored this species to the early name *S. majus*. As made clear by that author, the plants known in the older American literature under the name *S. longifolium* really belong to *S. majus*.

The large example figured here has leaflets 26 mm. long, 15 mm. wide at the top. The stem is comparatively slender. The leaflets are only slightly rounded at the distal border, and are not bifid. A smaller specimen has leaflets 13 to 14 mm. long, 10 mm. wide, most of them deeply lacinate.

Formation and locality: Cherokee shales, Lansing.

GYMNOSPERMÆ.

CORDITALES.

Cordaites UNGER.

Cordaites communis Lx. Pl. LIX, fig. 2.

Cordaites communis Lesquereux, Proc. Amer. Phil. Soc., vol. 17, p. 320; David White, Flora Lower Coal Measures of Missouri, p. 260, pl. 3, fig. 1; pl. 16; pl. 46, 1899.

Leaves long, spatulate, when mature over 30 cm. in length; gradually narrowed to a semicircular clasping base, gradually widened upward, broadest part a little below the apex, 3½ or more cm. Primary nerves prominent at the base, 15 to 18 per centimeter, interstriæ numerous, apex of the leaf obtusely rounded.

The species is fairly abundant in the Le Roy shales at Blue Mound. The basal part of the large leaf, figure 2, plate LIX, seems to indicate a form with more slender base than that found in the Lower Coal Measures at Clinton, Mo., as figured by White, *loc. cit.*

Cordianthus GRAND 'EURY.

Cordianthus ovatus Lx.

C. ovatus is found in the Cherokee shales at Lansing and is particularly abundant in the Le Roy shales. It is found also in the Scranton shales.

Cordianthus sp. Pl. XLVII, fig. 10.

A small *Cordianthus* occurs in the Bethany Falls limestone near Kansas City.

Trigonocarpum BRONGNIART.

Trigonocarpum schultzianum Goep. and Berg. Pl. LII, fig. 1; pl. LVIII, fig. 3.

Numerous specimens of this species have been obtained from the Le Roy shales. These are 4 to 5 cm. long, 1 to 2 cm. wide, and have four or five costæ on a side. A seed, apparently of the same species, found at Lansing, is oblong, narrowed both to base and apex, the broadest part being about or a little below the middle. The costæ are indistinct; five or six are seen on the side. The original fleshy covering is represented by a distinctly coaly layer having a thickness of 2 cm. and traceable entirely around the seed.

Formation and locality: Cherokee shales, Lansing; Le Roy shales, Lawrence.

Rhadocarpos sp. cf. multistriatus (Presl.) Lx.

This single large seed is very poorly preserved. The characters of the specimen are poorly marked, possibly because of a non-resistant testa. The endotesta, or sarcotesta, surrounding it during life leaves its imprint of carbonaceous matter around the sides. Neither ribs nor striæ show on the testa, the whole being covered with a smooth carbonaceous layer.

This seed is very similar to a large seed from Clinton, Mo., with which I have compared it. The Clinton seeds are referred doubtfully by White to *Rhabdocarpos multistriatus*.

Formation and locality: Cherokee shales, Lansing.

Rhabdocarpos cf. emarginatus Lx. Pl. XLVII, figs. 1, 2.

The Le Roy shales contain at the Blue Mound and Haverkampf localities numerous seeds which are oblong in form, obtuse at the apex, narrowed to a short, thick, neck-like attachment at the base, 2 to 2½ cm. long, about 1 cm. wide, marked with numerous fine, more or less broken, striæ.

Formation and locality: Le Roy shales, Lawrence.

Cardiocarpon BRONGN.

Cardiocarpon Brongniart, Prodrome, p. 87 (pars), 1828.

Cardiocarpon sp. Pl. LI, figs. 12, 13.

Innumerable small seeds of the genus *Cardiocarpon* are found at the Haverkampf locality, one stratum being almost completely filled with them. They are almost orbicular in outline, slightly pointed at the apex. The specimen illustrated by figure 13 of plate LI is more pointed than is usual. This seed, lying in a concretion, still has the petiole by which it was attached preserved. The seeds are thin and flat, the nucleus indistinct, and often distinguished with difficulty.

Formation and locality: Le Roy shales, Haverkampf farm.

Cardiocarpon (Samaropsis) branneri Fairchild and D. W., Mss. Pl. LI, fig. 11.

The phase of this species in the Bethany Falls limestone at Kansas City, Kan., is so similar to the species as found in the Cherokee shales at Clinton, Mo., and so well described by David White (Flora of the Lower Coal Measures of Missouri, p. 266) that I quote his description: "Fruit small, oval or ovate, and slightly prolonged at the somewhat truncate base, 10 to 12 mm. long, 7 to 9 wide, consisting of an ovate nucleus within a relatively wide wing; wing oval, blunt, and incised a little, or very slightly emarginate at the apex, sometimes slightly rounded on

it differs from the specimens described by Zeiller. The fine-grained sand in which the fossil is embedded had partly filled the hollow before the organ became compressed. The specimen has a radius of 8½ cm. The main ribs are thicker and stand out more prominently than those of the specimen from the French Coal Measures, although otherwise the two specimens agree closely except for the apparent lack of symmetrical development in the European specimens which Zeiller has so well described and illustrated.

The numerous specimens from the Elmdale formation which Mr. White has kindly offered for study present considerable variation from this type and from each other. In size they vary from a few centimeters to probably not less than 30 centimeters when complete. The number of ribs at the base varies from three to six. The border has the appearance of being drawn out to a very thin edge, and it is in many cases impossible to trace it to its termination. The most interesting character in connection with these specimens is a certain pitting and marking of the surface which resembles very much the impressions left by sporangia. The pits have the appearance of medium-sized sporangia arranged in a circle about an elevated central point of attachment much like that of a number of Marrateaceous ferns. Unfortunately the preservation is not such as to clear up all doubts regarding these impressions; they are, however, entirely similar to those left by sporangia in a matrix of this nature. A careful search has been made for spores retained in place within the sporangia, but without success, as the sandy nature of the matrix hardly permits the preservation of spores in mass within the sporangia. A bit of the surface removed to a microscope slide was found in one instance to contain a large spore, the reference of which, however, to this plant could not be established.

If the pittings on the surface subsequently prove to be impressions left by sporangia a considerable advance will have been made in the attempt to understand this entirely enigmatic fossil. Zeiller's conception of the organ is that it is probably made up of six cuneiform leaves united by their lateral edges. It seems also possible that the organ is simply one large peltate frond or leaf with the petiole attached at the center, a hypothesis that would more readily account for the variable number and arrangement of the main ribs.

Daubreeia pateræformis (Germar) Zeiller (?). Pl. LII, figs. 1, 2; pl. LV, fig. 4; pl. LVI, fig. 5; pl. LVIII, fig. 1.

Owing to the uncertainty which still exists concerning the nature of this fossil, and the limits of variation to be expected within a species, it is impossible at present to do more than make an approximate reference of the American material. It may be said, however, that the specimens which have come to light in this country are in their general organization essentially like those of the French Coal Measures. Such differences as they present may, when better known, prove to be the result of differences in preservation, rather than varietal or specific characters. The specimens obtained from the Le Roy shales are more nearly in agreement with the Commentry specimens, and except for somewhat larger ribs appear to agree in all essential characters. The Onaga specimens are, however, more doubtful, not only on account of their great range in size and structure, but from the fact that three to five seem to be the common number of ribs developed on these forms.

Formation and locality: Le Roy shales, Lawrence, and Elmdale formation, Onaga.

Genus undt. Pl. LI, figs. 7, 10.

A characteristic plant of an undetermined genus is not at all uncommon at the Haverkampf locality in the Le Roy shales. The fronds are very delicate, evidently of considerable length, none having been seen complete. The frond is flexuous, divided by dichotomy at more or less regular intervals, and is traversed by a single median strand.

Fungi.

Hysterites sp. Pl. XLVI, fig. 8.

The linear, elliptical or elongate marks which often occur on the leaves of *Neuropteris scheuchzeri* seem by their shape to belong to the genus *Hysterites*. The plant figured by Bunbury (Quart. Jour. Geol. Soc. 3, pl. 21) as *N. cordata* is, as stated by Fontaine and I. C. White, referable to *N. Scheuchzeri* (*hirsuta*), and the scars occurring on it are the same as commonly occur on this species, and, as Bunbury says, are the result of disease. Numerous specimens of *N. scheuchzeri* from the Le Roy shales show this fungus. The fungus occurring on *Cordaites* is apparently a similar species.

Excipulites neesii Goep.

This fungus is found on many fronds of *Pseudopecopteris pluckenetii* from the Chanute and the Le Roy shales.

it differs from the specimens described by Zeiller. The fine-grained sand in which the fossil is embedded had partly filled the hollow before the organ became compressed. The specimen has a radius of 8½ cm. The main ribs are thicker and stand out more prominently than those of the specimen from the French Coal Measures, although otherwise the two specimens agree closely except for the apparent lack of symmetrical development in the European specimens which Zeiller has so well described and illustrated.

The numerous specimens from the Elmdale formation which Mr. White has kindly offered for study present considerable variation from this type and from each other. In size they vary from a few centimeters to probably not less than 30 centimeters when complete. The number of ribs at the base varies from three to six. The border has the appearance of being drawn out to a very thin edge, and it is in many cases impossible to trace it to its termination. The most interesting character in connection with these specimens is a certain pitting and marking of the surface which resembles very much the impressions left by sporangia. The pits have the appearance of medium-sized sporangia arranged in a circle about an elevated central point of attachment much like that of a number of Marrateaceous ferns. Unfortunately the preservation is not such as to clear up all doubts regarding these impressions; they are, however, entirely similar to those left by sporangia in a matrix of this nature. A careful search has been made for spores retained in place within the sporangia, but without success, as the sandy nature of the matrix hardly permits the preservation of spores in mass within the sporangia. A bit of the surface removed to a microscope slide was found in one instance to contain a large spore, the reference of which, however, to this plant could not be established.

If the pittings on the surface subsequently prove to be impressions left by sporangia a considerable advance will have been made in the attempt to understand this entirely enigmatic fossil. Zeiller's conception of the organ is that it is probably made up of six cuneiform leaves united by their lateral edges. It seems also possible that the organ is simply one large peltate frond or leaf with the petiole attached at the center, a hypothesis that would more readily account for the variable number and arrangement of the main ribs.

Daubreeia pateræformis (Germar) Zeiller (?). Pl. LII, figs. 1, 2; pl. LV, fig. 4; pl. LVI, fig. 5; pl. LVIII, fig. 1.

Owing to the uncertainty which still exists concerning the nature of this fossil, and the limits of variation to be expected within a species, it is impossible at present to do more than make an approximate reference of the American material. It may be said, however, that the specimens which have come to light in this country are in their general organization essentially like those of the French Coal Measures. Such differences as they present may, when better known, prove to be the result of differences in preservation, rather than varietal or specific characters. The specimens obtained from the Le Roy shales are more nearly in agreement with the Commentry specimens, and except for somewhat larger ribs appear to agree in all essential characters. The Onaga specimens are, however, more doubtful, not only on account of their great range in size and structure, but from the fact that three to five seem to be the common number of ribs developed on these forms.

Formation and locality: Le Roy shales, Lawrence, and Elmdale formation, Onaga.

Genus undt. Pl. LI, figs. 7, 10.

A characteristic plant of an undetermined genus is not at all uncommon at the Haverkampf locality in the Le Roy shales. The fronds are very delicate, evidently of considerable length, none having been seen complete. The frond is flexuous, divided by dichotomy at more or less regular intervals, and is traversed by a single median strand.

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Excipulites neesii Goep.

This fungus is found on many fronds of *Pseudopecopteris pluckenetii* from the Chanute and the Le Roy shales.

THE PERMIAN FLORA OF KANSAS.
Description of Genera and Species.

PTERIDOPHYTA.
FELICALES.
Pecopteris BRONGNIART.

Pecopteris arborescens Brongn. Pl. LXI, fig. 2.

This species is rather abundant at the Banner City locality. The form seems to be that typical of the species as developed in the Upper Coal Measures and the Lower Permian, having pinnules at right angles to the rachis, or nearly so, close or contiguous. Midvein straight, not decurrent. Lateral veins simple, arched slightly in passing to the borders. The impressions of the sporangia are preserved occasionally, the sorus consisting usually of four sporangia grouped around a central point of attachment. The primary rachis is incrusted with a mineral deposit obscuring the punctæ.

Formation and locality: Wellington shales, Banner City, Dickinson county, Kansas.

Pecopteris cf. cyathea (Shloth.) Brongn. Pl. LXI, fig. 3.

Some doubt has been expressed by authors as to whether *P. arborescens* and *P. cyathea* are to be regarded as distinct species. Most of the Wellington specimens agree with ***P. arborescens*** in the limited sense of that species. A few specimens are found, however, which seem to represent the ***P. cyathea*** form as characterized by Zeiller.[292] The pinnæ have much the same form but the pinnules are more slender, having forked veins, the upper division sometimes again branched.

Formation and locality: Wellington shales, Banner City, Dickinson county.

Pecopteris cf. hemiteloides Brongn. Pl. LXI, figs. 4-6.

Two specimens occur in the collection having in the shape of the pinnules and in the venation a very close resemblance to *P. hemiteloides.*

292. These two species have already been discussed somewhat fully in the section on Coal Measures flora.

Formation and locality: Wellington shales, Banner City, Dickinson county. Also obtained from the Elmdale (Upper Coal Measures) at Onaga (David White, Bull. 211, U. S. Geol. Survey).

Callipteris BRONGN.

Callipteris whitii sp. n. Pl. LXI, figs. 8-11; pl. LXVI, fig. 3.

Fronds apparently large, bipinnate or more. Penultimate pinnæ large, sloping gradually to the apex. Rachis strong, apparently round. Ultimate pinnæ alternate, close, often touching or overlapping at the base, open or inclined forward slightly, lanceolate to linear, broadest at the base, smaller ones decurrent, obtuse at the apex. Apex capped by a small ovate terminal pinnule, or sometimes truncate, formed by the union of two lateral pinnules, with a slight constriction in the middle. Ultimate pinnæ evidently reaching a very considerable length, at least 10 cm. The pinnæ are gradually reduced in length toward the apex of the frond, passing at last from small pinnæ into pinnatifid and undulate pinnules. Rachis round, depressed, strong, decurrent at its union with the rachis of next larger division. Pinnules alternate, close, larger ones more distant, open or oblique, sessile by the entire base, connate at the base in the smaller pinnules, free almost or quite to the base in the larger; decurrent, smaller ones prominently so, larger ones having the basal lobe on the under side of the first lower pinnule attached in part to the rachis of the pinna, smaller pinnules ovate, larger elongate with obtuse apices; borders of the entire pinnules slightly rolled, of the lobate ones distinctly so; borders of the small pinnules entire, of the larger undulate, and of the largest constricted, forming ovate lobes. Constrictions forming the ovate lobes marked off by a thin depressed line running more than half way to the rachis. In the cast, this line is prominent, running as a raised line from the constriction between the lobe to near the midrib. As a result of the manner of development of the frond the pinnules vary exceedingly in size, according to their position. Although merely ovate lobes on the small pinnæ, they reach further down on the frond a length of 10 to 12 mm. The pinnules are about 3 mm. wide, elongate in shape, with an obtuse apex; lower on the fronds they reach a length of 12 to 14 mm. with a width of about 4 mm. The pinnules of this size have five or six ovate lobes on each side, the basal

one on the lower side being decurrent and united with the rachis. Midvein rather strong, continuing to near the apex, where it becomes a shallow furrow, decurrent at the base. Lateral veins not distinct; they leave the midrib at an angle of approximately 45 degrees, curve outwards to the border, apparently forking once, or simple in the smaller pinnules. The veins passing into the lobes of the lobate pinnules fork once. The species is named for Mr. David White.

Formation and locality: Wellington shales, Banner City, Dickinson county.

Callipteris elongata sp. nov. Pl. LXI, fig. 16.

Ultimate pinnæ linear. Pinnules alternate, very oblique, curved back a little at the apex, decurrent, oblong, obtuse at the apex, largest a little above the middle, contracted at the base, rounded above the base, borders sinuous, texture thin. Venation fine. Midvein continuing to the apex, decurrent at the base, entering the pinnule near the upper side of the base. Lateral veins oblique, those on the upper side nearly straight or but slightly curved, those on the lower side somewhat more curved, forked. Rachial veins supply the decurring base.

This species is not abundant, a few specimens only having been obtained. The most closely related form that has come to my notice is from the Lower Permian of Italy, figured by Stefani (Flora Carb. et Perm. della Toscany, pl. 8, fig. 7) as a form of *Callipteris conferta*.

Formation and locality: Wellington shales, Banner City, Dickinson county.

Callipteris sp. Pl. LXIV, fig. 2.

The frond or division of a frond illustrated here and belonging with little doubt to the genus *Callipteris* resembles types of that species found in the Permian of France and figured by Zeiller (Bassin d' Autun and d' Epinac), although apparently specifically distinct from any of these, from all of which it differs in having a petiolate frond or division of a frond with the pinnules toward the base reduced.

Formation and locality: Wellington shales, Banner City, Dickinson county.

Callipteris conferta Sternb. Pl. LXI, figs. 12, 13; pl. LXIII, fig. 9; pl. LXIV, fig. 5.

C. conferta is one of the very abundant species in the Permian collections. The pinnules seen from above have a smooth

coriaceous appearance, the midvein of the pinnule showing as a slight depression. The under side has usually a rough, wrinkled appearance, the midvein marked by a projecting line. The line referred to by Professor Weiss[292] as running obliquely from the incision between the pinnules to the rachis is very distinct on well-preserved specimens, and runs to the midvein of the pinnule near or at its base or unites with the rachis of the pinna near the origin of the midvein of the pinnule. The pinnæ in the middle part of the frond are oblique, 2 cm. apart; the pinnules alternate, contiguous for some distance, 8 to 11 mm. long, oblique, and recurved at the apex. Near the apex of the frond the pinnules are closer, connate, and decurrent along the rachis. The lateral veins are usually indistinct; they are oblique, slightly curved, simple, or occasionally forked.

The variety *C. conferta obliqua* Goep. is apparently present, as is also *C. conferta patens* Weiss and *C. conferta vulgaris* Weiss.

Formation and locality: Wellington shales, Banner City, Dickinson county, and the Wreford limestone, six miles west of Reece, Chase formation, Washington, and from the Elmdale shales, near Reece.

Callipteris (?) sp. Pl. LXI, fig. 15.

A small part of a frond from the Wellington indicates apparently a *Callipteris* of the type of the genus largely developed in the Permian. The pinnules are subopposite or opposite, open, almost at right angles or sessile, gradually reduced in approaching the petiolate base, the lower pair being very small. The lamina is thick and the venation in this specimen entirely obscured. The fragment has some resemblance to the small species of *Glenopteris* and may prove to belong to that genus.

Formation and locality: Wellington shales, Banner City, Dickinson county, and the Wreford limestone, six miles west of Reece.

Callipteris cf. bergeroni Zeiller. Pl. LXI, fig. 7; pl. LXV, fig. 1.

This *Callipteris* has a striking resemblance to *C. bergeroni* from the Permian of Lodeve, France. The pinnules are, however, larger, and the rachis stronger.

292. Flora des Jungs. Steinkohlen und des Rothliegenden, p. 75.

Formation and locality: Wellington shales, Banner City, Dickinson county.

Glenopteris SELLARDS.

Kansas University Quarterly, vol. 9, pp. 179-189, July, 1900.

Fronds pinnatifid, or simply pinnate, elliptical in outline, tapering to base and apex. The fronds of the different species of the genus have a very considerable range in size, from 10 to 15 cm. for the smallest species to 45 cm. or more for the largest. Base always petiolate; rachis strongly developed, proportionately strong at the base, longitudinally striate. Fronds, apparently thick and fleshy in life, leaving a carbonaceous layer on the rock, in which the veins are deeply immersed and often hidden. Pinnules attached to the rachis by the entire base, decurrent, or auricled below, more or less rounded above. Pinnules at the base of the frond reduced, open, or more commonly reflexed. Those at the middle of the frond largest, varying in size and shape with the size of the frond, oblong to linear, oblique, or curved back at the apex. Borders entire or undulate, and even lobate in one species referred doubtfully to the genus. Pinnules towards the apex also reduced, becoming more ovoid, even odontopteroid in appearance, ending in undulations of a terminal pinnule. Midvein of the pinnule strong in the large fronds, decurrent at the base, running some distance down the rachis before uniting with it, continuing to or near the apex. Lateral veins oblique, rather thin, and often obscured by the thick frond; simple or forking; at the base attached to the main rachis; curved in passing to the border, or almost straight. The decurring wing, or auricle, receives numerous strongly curved, or straight, simple, or forked, nerves from the main rachis. Fructification unknown.

The plants of this characteristic genus are among the most abundant of the formation. Five species have been found, represented by good specimens. In addition, there are two specimens in the collection, one the apical part of a frond, the other a young frond still in the circinate condition at the apex, which apparently are not referable to any of the species described. The pinnules of both are linear, very acute, straight, and oblique to the rachis. The numerous individuals, and the differentiation that the genus has reached, indicate that it was a leading genus in the flora of the formation.

Generic relation.—Among Paleozoic plants, the genus most closely related to *Glenopteris* in the form and development of

the frond is *Protoblechnum* Lesqx. The type, and only species of *Protoblechnum* known, comes from near the base of the Coal Measures, at Rushville, Ohio, and was first described as *Althopteris holdeni* by Andrews.[293] Lesquereux afterward made Andrews's species the type of the genus *Protoblechnum* Lesqx. *P. holdeni* (And.) Lesqx. has, like the species of *Glenopteris*, sessile, auricled pinnules, reduced at the base of the petiolate frond. The estimated length of this species, 50 to 60 cm., is only slightly larger than that of the largest species of *Glenopteris*. The apical part of the frond of *Protoblechnum* differs, however, entirely from that of *Glenopteris*. In the several species of *Glenopteris* the pinnules are reduced gradualley toward the apex of the frond, at last uniting with a terminal pinnule. The frond of *Protoblechnum* is represented as ending abruptly, the pinnules not at all reduced. It might be suspected that the apex of the specimen was gone, especially as the rachis continues moderately strong to the very last, were it not that both authors agree in describing the frond as complete. Lesquereux says (Coal Flora, p. 188): "The upper ones (pinnules) are close, less distinctly scythe-shaped, but quite as long, the terminal leaflets being still 6 cm. long." The venation of *Protoblechnum* Lesqx. is apparently distinct, the veins twice forked; the venation of *Glenopteris* is indistinct, and often obliterated, the veins simple or forked once. The thick coating of scales on the rachis of *Protoblechnum* is a character not seen on any species of *Glenopteris*.

Glenopteris cannot be closely compared with any other genus of Carboniferous ferns. It has, however, in the sessile decurrent pinnules, a general relation to all the genera of the alethopteriod group, to which it accordingly finds its most natural reference. The relation after *Protoblechnum* Lesqx. is perhaps closest to *Alethopteris* St. But the genus differs from all the other alethopterids, again excepting *Protoblechnum*, in the simple fronds and large pinnules. *Glenopteris* has a suggestive resemblance to some of the callipterids, especially species of *Callipteris* having large pinnuled fronds. The apices of the fronds of *Glenopteris* have a peculiar resemblance to *Odontopteris*. So striking is this resemblance in *Glenopteris simplex* that the apex, if found detached, unassociated with the rest of the frond, would probably be taken for a large

293. Geol. Survey of Ohio Pal., vol. 2, p. 420, pl. LI, figs. 1-2*a*.

Odontopteris; but the frond as a whole is very different from that genus. There is a resemblance perhaps worth noting between *Glenopteris* and the smaller species of *Megalopteris* Dawson in the sessile decurrent pinnules, but the rigid fronds of Glenopteris, with strong axial development, are very different from the fronds of *Megalopteris*, which are large, and often bifurcate at the top.

Glenopteris has, in the shape and development of the frond, a very striking resemblance to the Mesozoic genera *Lomatopteris* Sch. and *Cycadopteris* Zigno. The resemblance of the large species of *Glenopteris* to *Lomatopteris* is especially close. The form and method of development of the frond in the two genera are very similar. Both have a strong, roughly striated rachis, and pinnules reduced at the base of the petiolate frond. *Lomatopteris* is described by Schimper as having its venation entirely obscured; the venation of *Glenopteris* is always indistinct, and in *G. lobata* entirely concealed. The auricled base, which distinguishes most of the species of *Glenopteris* from *Lomatopteris*, is wanting in *G. lobata*. This latter species further resembles *Lomatopteris* by a very similar lobation of the borders. The essential character separating this species from that genus is the absence of the thickened border.

White[294] has already suggested the possible relation of the Alethopterideæ with the Triassic genera *Lomatopteris* and *Cycadopteris*. The genus *Glenopteris* from the Permian having an evident relation to both *Protoblechnum* from the Coal Measures, and to *Lomatopteris* and *Cycadopteris* from the Trias, makes such a relation much more probable. As far as it is possible to conclude from the evidence of sterile fronds, these three genera seem to have a direct genetic relation.

Glenopteris splendens Sellards.

Kansas University Quarterly, vol. 9, pp. 182-184, pl. 37, fig. 1; pl. 40, 1900.

Fronds large, deeply pinnatifid, slightly curved or straight, coarse, spreading, broadly elliptical, 45 or more cm. long, with a spread of about 20 cm., thick in life, leaving a dark carbonaceous layer on the rock, petiolate, broadest in the middle, tapering to base and apex. Rachis strong, rigid, continuing well towards the apex of the frond, roughly marked with longitudinal striæ; in the fossil condition flat, or the original more or

294. Bull. Geol. Soc. Am., vol. IV, 1893, p. 119.

less cylindrical shape indicated by a depression in the stone, about one-third wider than deep, partly filled with carbonaceous matter. Petiole of the frond very strong, striate, 1 cm. wide at the base, broken off short, as if detached from an arborescent stem or possibly a larger division of the frond. Pinnules close, connate or overlapping at the base, alternate or subopposite, oblique to the main rachis, or lower ones reflexed, linear; base sessile, decurring or strongly auricled below, somewhat rounded above, borders entire, straight, and nearly parallel. Pinnules sloping very gradually from the base to the obtuse apex, varying much in size and shape according to the position on the frond; those at the middle reaching a length of 13 cm. and a width of 2 cm. at the base, strongly auricled, the auricle overlapping two-thirds of the distance to the midrib of the next pinnule below; those at the base of the frond open or reflexed, more narrow in proportion to their length, less distinctly auricled or merely connate, or even distinct; those toward the apex also reduced, broader in proportion to their length, becoming near the apex broadly oblong, oblique, with decurring base, 1 or 2 cm. long, 1 cm. or more wide. Midvein of the pinnule broad but shallow, continuing two-thirds the length of the pinnule, then gradually fading out. The center of the furrow is marked by a narrow depression, which shows in the cast of the upper side of the frond as a fine, distinct line running through the center of the pinnule. Lateral veins indistinct, thin, almost hidden in the epidermis. They leave the midrib obliquely, curve outwards, and meet the borders almost at right angles, simple or forked once, 12 to 14 per cm. The veins of the auricles are strongly curved, often once forked. Occasionally the auricle shows a very slight constriction of the base of the pinnule, as if about to become lobed.

On the rachis of one specimen of this species there occurs a narrowly elongate scar, 3 mm. long and less than a half mm. wide. A similar but smaller scar occurs on the rachis of a fragment probably referable to this species. These scars are of interest, because of their seeming identity with numerous such scars occurring on or near the rachis of some of the tæniopterids of the collection, which in turn at least resemble the scars on *Macrotæniopteris*, described as probable fructification by Fontaine.[295]

295. Monograph, Older Mesozoic Flora of Virginia, p. 18.

These scars will be more fully described in treating of the tæniopterids of the formation.

Formation and locality: Wellington shales, Banner City, Dickinson county.

Glenopteris simplex Sellards.[296]

Fronds small, 10 to 15 or more cm. long, simply pinnatifid, narrowly elliptical in outline, short petiolate, broadest in the middle, tapering to base and apex. Fronds apparently thick, leaving a thick carbonaceous layer on the rock; very variable in size; always curved from the base, often decidedly so, inequilateral in development, due to the excessive growth of the pinnules on the convex side of the frond. Pinnules alternate, decurrent at the base, joining the pinnule below by a winged projection, or by a more or less distinct auricle, rounded above the base, in general, oblique to the rachis; in the young frond the pinnules are close, oblique, ovate, or oblong; as the frond develops the pinnules become more distant, oblong, still leaving the rachis obliquely, but curved back at the apex; in the largest fronds the pinnules are 1 cm. distant, 3 to 4 cm. long, curving back decidedly at the apex, giving the frond a lax appearance. Pinnules at the middle of the frond largest, distinctly curved. Apex very obtusely rounded. Borders entire, straight, or irregularly undulate. Pinnules at the base of the frond much reduced; lower ones, which are 1 or 2 cm. from the base, mere wing-like projections, 3 or 4 mm. long. Pinnules also reduced towards the apex, becoming ovate, odontopteroid in appearance, passing into undulations of a lanceolate, obtuse, terminal pinnule. The terminal pinnule is characteristic. It is large in proportion to the frond, somewhat irregular in shape, sloping slightly to an obtuse apex. In a frond 15 cm. long, the terminal pinnule is 2 cm. long. Midvein distinct, decurrent, running down the rachis 1 or 2 mm. before uniting with it, continuing almost to the apex. Lateral veins oblique, strong, simple or forking once, almost straight or distinctly curved, 10 or 12 per centimeter at the border. Veins strongly curved in passing from the rachis to the auricled base. The midvein of the pinnule becomes less marked in pinnules nearing the apex of the frond, lateral veins more pronounced, passing gradually into the lateral veins of the terminal pinnule.

This species, the smallest of the genus, is common, and its

296. Kan. Univ. Quarterly, pp. 184, 185, pl. 37, fig. 2; pl. 38, figs. 2, 3; pl. 39.

general form usually well preserved. The venation, however, is indistinct on most of the specimens. One frond, fortunately, has the venation well preserved. The rachis, seen from the upper side, is marked by a broad, shallow groove; from below it presents a broken, striate appearance, due to the decurring midveins of the pinnules. With several good specimens at hand, it is possible to follow the development from the young to the full-grown frond. The pinnules, at first close, ovate, and oblique, become, by the growth of the frond, more distant, elongate, curved back at the apex, lax in appearance, reaching at last an extremely curved form.

Formation and locality: Wellington shales, Banner City, Dickinson county.

Glenopteris lineata Sellards.[297]

Fronds of medium size, deeply pinnatifid or pinnate, somewhat fleshy, narrowly elliptical, narrowing gradually to a long apex, petiolate at the base. Rachis strong, longitudinally striate or wrinkled, half cylindrical or flattened, broken off short at the base. Pinnules alternate, close, or more distant in the middle of the frond, rounded above the base, united by a decurring wing to the pinnule below, situated very obliquely on the rachis, linear-lanceolate, straight, very symmetrical above the base, narrowing gradually and regularly from the base to the apex; borders straight and entire, apex rounded, or cut off wedge shaped. Pinnules reduced in passing to the apex, becoming shorter, proportionally wider, at last not more than 5 or 6 mm. long, 4 or 5 mm. wide, and triangular in shape. Midvein of the reduced pinnule still evident, continuing to the apex. Pinnules also reduced towards the base of the frond as in other species of the genus, lower pair reflexed. Midvein straight, deep, and narrow, deeply immersed, continuing quite to the apex of the pinnule, decurrent at the base; lateral veins obliterated in all the specimens yet obtained by the thick, longitudinally wrinkled substance of the frond.

The species is described from four specimens, two of them representing the apical part of the frond, but with the extreme apex of both broken; the other two specimens represent the middle and basal parts of the frond.

Formation and locality: Wellington shales, Banner City, Dickinson county.

297. Kan. Univ. Quarterly, vol. 9, pp. 185, 186, pl. 37, fig. 3; pl. 38, figs. 4, 5, 1900.

Glenopteris sterlingi Sellards.[298]

Fronds large, deeply pinnatifid, the pinnules connected at the base by a lobate auricle, strong, rigid in appearance; elliptical, broadest in the middle, 25 or more cm. long; petiolate, thick, leaving a carbonaceous layer in which the veins are mostly hidden. Rachis strong, half-cylindrical or compressed in the cast, 1 cm. broad at the base, longitudinally striate. Pinnules close, opposite or subalternate, unsymmetrical, much enlarged above the base, sloping at first abruptly, then gradually, to a lanceolate apex, situated at right angles to the rachis, straight, or curving up slightly at the apex, scythe-shaped, 10 to 17 mm. distant, 6 to 7 cm. long in the middle of the frond, sessile at the base, connected by a lobate auricle. Borders entire, straight or irregularly undulate. Apex small, rounded. At the center of the frond the lobes between the pinnules are approximately twice as long as broad, about 9 mm. long, 4 or 5 wide, half cut off from the pinnule above by a sharp incision at the base of the pinnule, connate with the pinnule below, or the outer part of the lobe overlapping slightly. In the pinnules approaching the base of the frond the lobes are progressively less strongly developed, entirely disappearing on the reduced basal pinnules. Main rachis of the frond brokenly and roughly striate throughout its entire length. Midvein of the pinnule moderately strong, continuing to near the apex, straight or nearly so, joining the rachis with a short downward curve. Lateral veins indistinct; those of the auricles best preserved. These leave the rachis with a slight curve, run straight and apparently simple to the border. In the first auricle six veins can be counted in the distance of 3 mm. On some of the pinnules of an eroded specimen the lateral veins show indistinctly. They leave the midvein obliquely and curve in passing to the borders; whether simple or forked, cannot be made out.

Two specimens of this species are found in the collection. The smaller one is well preserved and covered by a thick coaly layer, entirely obscuring the venation except in the lobes of the auricles. This specimen shows well the distinct lobe between the pinnules. The second specimen is of an eroded frond, somewhat defaced. The lobate base, however, is well shown on some of the pinnules. The species has a very different appearance from others of the genus, due to the odd shape of the pinnules and their lobate bases. One large specimen

298. Kan. Univ. Quarterly, vol. 9, pp. 186, 187, pl. 41; pl. 42, fig. 1, 1900

has evidently the natural shape of the frond, except that the apices of the pinnules are broken and somewhat displaced. The frond is rigid, strongly curved at the base, and again less strongly curved in the opposite direction at the apex. The extreme apex is not preserved.

The first specimen of this species was collected by Mr. C. Sterling, for whom the species is named.

Formation and locality: Wellington shales, Banner City, Dickinson county.

Glenopteris lobata Sellards.[299]

Fronds large, pinnate, petiolate, coriaceous. Rachis strong, flat, striate, 1½ cm. wide, broken off short at the base. Pinnæ close, alternate or subopposite, linear, sessile, and overlapping at the base, 1½ cm. apart, longest 6 cm., divided into numerous small, ovate, shallow, but distinct lobes. Basal pinnæ reduced, scarcely or not at all lobed, lowest pair much reduced, 1½ cm. long, reflexed. Lobes more distinct on the lower side of the pinna than on the upper, true at least of those pinnæ approaching the base of the frond. First lobe on the lower side of each pinna attached to the main rachis. Midvein of the pinna broad, but shallow, marked on the upper side of the frond by a shallow furrow continuing to near the apex, curved down at its union with the rachis. Lateral veins entirely obscured by the coriaceous frond.

This species, as noted in the discussion of the genus, approaches very close to *Lomatopteris* Schimper. As in that genus, the veins are obscured, frond thick petiolate, rachis strong and striate, pinnæ lobed. The absence of a thickened border of the pinnules is one of the important characters separating this species from Schimper's genus. *Lomatopteris burgondiaca* may be compared as a species closely related in the form of its fronds.

Formation and locality: Wellington shales, Banner City, Dickinson county.

Tæniopteris BRONGNIART.
Prodrome, p. 61, 1828.

The genus *Tæniopteris* is well represented in number of specimens in the Kansas Permian flora. Two species and one variety have been recognized. The genus as developed in the Kansas Permian has been described by me in an earlier paper

299. Kan. Univ. Quarterly, vol. 9, pp. 187-189, pl. 37, fig. 4; pl. 42, fig. 2, 1900.

(Kan. Univ. Quart., vol. 10, pp. 1-12, January, 1901.) The description of species is here given without change from that paper. In the earlier paper a rather full account is given of small oval bodies occurring between the veins of *Tæniopteris*, and of scars on the rachises and lamina. The interneural bodies are small, oval, hard, lie midway between the veins, half immersed in the lamina of the leaf. They occur on both species of the genus. The size and number of these bodies seem to be characters of specific value. On the group of specimens which I have referred to *T. coriacea* they are proportionally large, readily visible to the eye, more distant and fewer than in the other species. Those on *T. newberriana* are smaller—although the fronds are larger—closer together, and scarcely visible without the aid of a lens. The bodies are readily removed from the frond. On touching the epidermis with molding-wax many of the small bodies adhere and may be transferred to the desired media for sectioning. Hardened balsam proved most successful as an imbedding medium. The sections made failed to reveal cellular structure in the bodies.

More or less similar interneural bodies have been observed on several genera of fossil plants. Those on *Tæniopteris* are, however, apparently unlike all others in that they are so preserved as to admit of removal from the frond. Some species of *Nilsonia* Brongniart, a Mesozoic genus referred by some to the cycads, by others to the ferns, have dots between the veins very suggestive of those of *Tæniopteris*. The dots of *Nilsonia polymorpha* Schenk are described as small, situated at approximately regular distances apart, and between the veins. These have been variously regarded by different authors. Schenk[300] regarded them as the remains of sori, and accordingly referred the genus to the ferns. Saporta considered them more like fungi,[301] and referred the genus again to the cycads. Count Solms Laubach, in summing up the evidence (Fossil Botany, p. 140, Balfour's translation), considers Schenk's view more probable than Saporta's, and therefore treats of the genus among the ferns. Later writers have generally referred the genus to the cycads. Those specimens of *Nilsonia polymorpha* having unsegmented pinnæ have, as has been often observed, a striking resemblance to *Tæniopteris* in

300. Die fosile Flora der Grenzschichten des Keupers und Lias Frankens, 1868.

301. Paleontologie francaise, ser. 2, vegetaux, vol. 2, 1875.

the form and venation of the pinnule, in the apical part of which the main vein is reduced to a mere line, but continues to the apex. The lateral veins are straight, mostly simple and arched upwards. The similarity is further increased by dots between the veins of both.

Occasional specimens of *Neuropteris* show dots more or less suggestive of those between the veins of *Tæniopteris*. Mr. David White has very kindly pointed out to me a specimen in the Lacoe collection of the National Museum which has numerous dots between the veins. *Alethopteris maxima* Andrews (Geol. Surv. Ohio, p. 421, pl. 50, figs. 3, 3*b*), a species from near the base of the Coal Measures of Ohio, is described as having numerous small dots between the veins. These were regarded by Andrews as probably dots of iron oxid. Lesquereaux (Coal Flora, p. 187) refers to them as "remnants or the base of scales similar to those often seen upon leaflets of species of *Acrostichum*." Dots occur between the veins of specimens of *Megalopteris harttii* and *M. dentata* from Rushville, Ohio. A specimen of *Alethopteris*, probably *A. serlii*, from Lansing, Kan., shows similar dots. In his report on the exploring expedition from Santa Fe to the junction of the Grand and Green rivers, Newberry figures (pl. 8, fig. 5) the apex of a frond with the following explanation: "*Tæniopteris* sp. (?) in fruit; summit of frond, Los Broncos, Sonora." The formation is considered Triassic. The specimen is not mentioned in the text. The figure is indistinct, but the dots seem to be small, close, and placed much as in the specimens from the Kansas Permian.

The possibility of these bodies being sporangia is discussed in the writer's paper referred to above. No additional information having been obtained, the question of their function must now, as then, remain an open one.

Several specimens of this genus bear on or near the rachis elongate-elliptical scars, resembling very closely those of *Macrotæniopteris magnifolia* (Rogers) Schimper as described and figured by Professor Fontaine in his "Monograph on the Older Mesozoic Flora of Virginia," page 18, plate 4, figures 1 and 1*a*. Two scars are seen in succession on the rachis of a specimen of *T. newberriana*. Professor Fontaine's description is taken from the depression, while in this specimen the scars project. The counter impression in wax seems to agree in every particu-

arating line. The venation of the smaller fronds seems thinner, but becomes proportionally stronger with the size of the frond. The apex, however, is decidedly more acute. The species and variety occur at the same locality.

Tæniopteris newberriana Fontaine and I. C. White.[303] Pl. LXIX, figs. 2, 4.

Numerous specimens in the collection are so close to *Tæniopteris newberriana* that their reference to that species, at least for the present, seems advisable. There are numerous individuals, but all more or less fragmentary. Owing to the thin texture of the frond the line of cleavage in the matrix is not sufficiently marked to expose it completely as in the last species. In this character of a very thin frond our specimens differ very markedly from the types of the species, which are described by the authors as rather thick and coriaceous. The fact that the matrix is different in the two cases, the Kansas specimens being preserved in limestone while the West Virginia ones were in shale, may account in part for this, and possibly for other seeming differences. The nerves are figured by the authors as leaving the rachis at right angles, but in the description they say that the lateral nerves leave "the midrib at a right angle, or with a very slight arch immediately at the insertion." In the Kansas specimens the veins near the apex of the frond leave the midrib at right angle, those near the middle with a slight arch immediately at the insertion, and those near the base with a more decided arch at the insertion. In the figures of the types the veins are represented as coming out at right angles from the rachis throughout the entire length of the frond, the base as well as the apex. No specimens have been found in the Kansas formation with the peculiar segmentation characterizing many of the West Virginia specimens. These two characters—difference in the origin of the veins, and absence of the segmented frond, may prove to be of specific value. The present reference is intended as suggestive rather than final. In other respects Fontaine and White's description of the venation, "lateral nerves very fine, closely placed and immersed in the parenchyma of the frond," entirely agrees with the Kansas specimens, as does also their description of the size and shape of the frond, "frond simple, elongate, narrowly elliptical, tapering slowly to the apex and base." The largest fronds of our

303. Penn. Second Geol. Surv., Permian Flora of West Virginia and Southwest Pennsylvania, p. 91, pl. 34, figs. 1-8, 1880; Sellards, Kan. Univ. Quart., vol. 10, p. 4, pl. 1, figs. 1-5, 7 and 13; pl. 4, fig. 4, 1901.

indicates that they are not the result of any accidental injury to the plant. It is difficult to make out with any degree of certainty what they are. They resemble some fungi rather closely. The possibility that they may be the result of pathological growth due to the puncture of an insect naturally suggests itself and, indeed, seems very possible. The scars made on the stem of the common false indigo (*Amorpha fruticosa*) quite similar to the scars on the stems of these plants first suggested to me the comparison with insect punctures. More recently I have been able to demonstrate that some of the Paleozoic insects were provided with a protruding ovipositor not unlike that of modern katydids. Numerous fossil insects have now been obtained in immediate association with the Kansas plants.

Figure 2, plate LXVII, shows another set of markings entirely on the lamina. They are elongate, or ovate-elongate, with the long axis parallel to the nerves, of varying size from very small to 5 or 6 mm., close or distant, project sensibly from the frond, usually with the carbonaceous layer rubbed off of the top. Some of the smaller ones are uninjured, and seem to show an elevated border with a depressed center. These scars are very suggestive of the work of the fungi.

The scars have an added interest because of their resemblance to scars on the type specimens of *Tæniopteris newberriana* from West Virginia, which Professors Fontaine and I. C. White regard as the bases of sori. In the West Virginia specimens the scars are placed in a single row along each side of the midrib, and the frond is divided into segments by deep, obtuse sinuses. Nothing of the segmented character has been observed on our specimens, and the large scars are more commonly on the midrib. These authors, however, compare the scars to those on *Macrotæniopteris magnifolia,* to which ours are very closely related. They say, Permian Flora, page 93, "*Macrotæniopteria rogersi* Schimper of the Richmond coalfield, contains, on specimens in our possession, elliptical depressions strikingly like the depressions seen on this plant, and shown on plate XXXIV, figure 3. In the specimen from the Richmond coal the depressions are larger, and are placed in one row *on* the midrib. Prof. Wm. B. Rogers, however, in his description of the plant, says that they often occur in rows, one on each side of the midrib." From their general resemblance there seems little doubt that the scars on the Kansas specimens are of the same nature as those on the West Virginia speci-

mens, and have no connection with fructification. In my earlier treatment of the genus I have compared the scars with *Hysterites* and *Rosellinites* among fossil fungi, and *Hysterium* and *Hysteriographium* among recent genera. The scars merit a more extended comparison with fossil and living fungi than I have been able to give them.

Tæniopteris coriacea Goep. Pl. LXVII, figs. 1, 2; pl. LXVIII, figs. 1, 2; pl. LXIX, figs. 1, 3.

Flora der Permischen Formation, p. 130, pl. 8, fig. 4; pl. 9, fig. 2, 1865-'66.

Tæniopteris coriacea Goep., Sellards, Kan. Univ. Quart., vol. 10, pp. 2, 3, pl. 1, figs. 6, 8-12; pl. 2, figs. 1, 2; pl. 3, figs. 1, 2; pl. 4, figs. 1, 3, 1901.

Fronds simple (?), linear or very narrowly elliptical, coriaceous in texture, broadest in the middle, tapering to a symmetrical lanceolate apex, and a petiolate base, 8 to 20 cm. long, average width at the middle, 10 to 20 mm. Rachis strong at the base, rough with rather strong longitudinal striæ, about 3 mm. wide, reduced gradually in passing to the apex where it becomes a mere line. Fronds slightly rolled at the borders. Lateral veins numerous, strong, straight and parallel, cross the lamina obliquely, with a slight but distinct upward curve at the border, 28 to 32 per centimeter. Veins near the base of the frond leave the rachis with a short curve, often forked once near their base; those at the middle of the frond only slightly curved at their union with the rachis, seldom forked; those near the apex not at all curved at their base, always simple, straight, or even arched upwards slightly in crossing the lamina. Oval bodies on several of the fronds, situated between the veins, half immersed in the epidermis of the frond, ½ to ¾ mm. apart, six or seven between each two veins. Elliptical elevations or corresponding depressions occur on or near the rachis of several specimens.

The species is a common one, and is represented by many good specimens. By reason of the thick, resistant texture, the frond is usually well preserved, and forms a natural line of cleavage in the matrix, which often breaks so as to expose its entire length. The individual specimens vary a good deal in size, but can usually be readily recognized by their straight, oblique, strong nerves, resistant texture, and lanceolate apex.

The agreement with Goeppert's types is not entirely complete, but essentially so. Goeppert's figures do not show a rolled border, nor does he mention such a character in his de-

scription; but this character is not always evident, and possibly not always present.

I have considered the frond as probably simple, as there are no indications of a pinnate character, and it has the same shape as other tænioptorids with supposedly simple fronds. The peculiarities of venation noted in the above diagnosis—veins near the base of the frond more curved at their union with the rachis, often forked, while those at the apex are only slightly curved, seldom forked—are seen also in the figures of the European specimens. The texture and shape of the fronds also agree. The fact that the oval bodies between the veins have not been previously observed may be due to the rarity of the species and the few specimens heretofore obtained. The scars on or near the rachis, whether the result of fungi or of insect stings, may have been absent on the European specimens.

The slightly thickened and rolled border of this species might be taken to indicate the presence of a border vein—a supposition to which the upward curve of the veins at the border adds strength. But if such a character belongs to the species it is not sufficiently preserved on any of the specimens at hand to be recognizable. Such a character, if it exists, would bring the species into comparison with the Mesozoic genus *Oleandridium*, some species of which it otherwise closely resembles.

The species seems to have been found as yet in only two other localities, both Permian, Ottendorf in Bohemia, and Lissitz in Moravia, both recorded by Goeppert (*loc. cit.*) The specimens known of the species heretofore have all been somewhat fragmentary.

Formation and locality: Wellington shales, Banner City, Dickinson county.

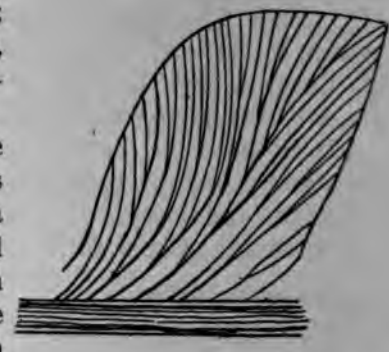
Tæniopteris coriacea var. **linearis** Sellards.[302] Pl. LXVIII, figs. 3, 4.

Fronds smaller, more narrowly linear, apex very acute, average width 7 to 20 mm., average length about 14 cm., thinner in texture, venation apparently thinner, and perhaps closer.

The difference between the extreme forms of this variety and the specimens typical of the species is very great, and if there were no intermediate forms would undoubtedly be considered of specific value. But between the extremely narrow fronds such as figured (plate LXVIII, figure 4,) and those typical of the species (plate LXVII, figures 1 and 2) there are such continuous gradations that I am entirely unable to draw any sep-

302. Kan. Univ. Quart., vol. 10, p. 3, pl. 8, figs. 3, 4, 1901.

wide. The basal pinnule on the lower side of each pinna is much enlarged, unequilateral oblong-ovate, deflexed, lying along the rachis, lower side straight and close to the rachis, upper side rounded. Veins originating from the rachis without a midrib, or the central vein merely stronger than others, spreading, several times dichotomous, fine, numerous; lower ones strongly arched, counting about 40 to the centimeter.



Pinnule of Odontopteris reichiana. Enlarged.

The Kansas specimens are very similar to the species as figured by Weiss (Foss. Flora der Jungs. Stien. Form.) and seem to agree essentially with the French specimens in the National Museum with which I have compared them. The deflexed basal pinnules, however, do not seem to have been previously observed, and the pinnules of the species as developed in the Wellington shales are rather large. The venation of one of the pinnules is shown in the accompanying text figure.

Formation and locality: Wellington shales, Banner City, Dickinson county; Chase formation, Washington. This species has been identified by Lesquereux from Thayer, Kan. (Recorded by White, Bull. U. S. Geol. Surv., No. 211.)

Odontopteris minor Brongn. Pl. LXII, fig. 17.

This species occurs rarely at the Banner City locality. It is one of the few species common to the Douglas formation and the Wellington shales.

SPHENOPHYLLALES.

SPHENOPHYLLEÆ.

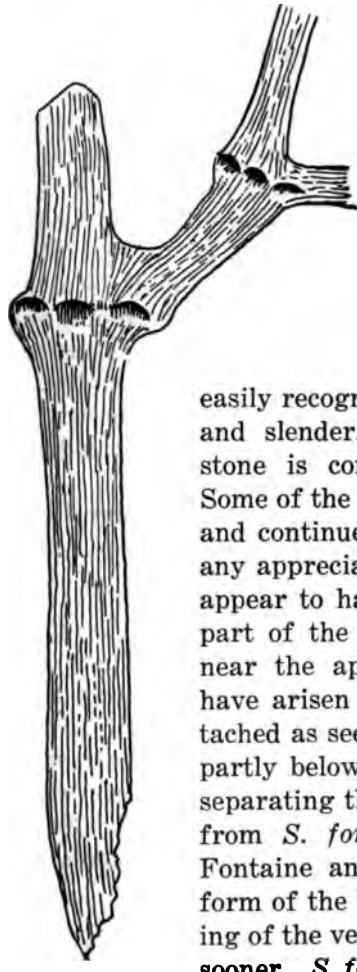
Sphenophyllum Brongniart.

Sphenophyllum obovatum sp. nov. Pl. LXI, figs. 17, 18; pl. LXIV, fig. 4.

Stems strong, marked by two or three furrows; internodes from a few mm. distant at the apex to more than 4 cm. on the large stems. Branches given off singly at the nodes, attached partly above and partly below the diaphragm. Leaflets

obovate, sides slightly concave, apices rounded, very obtuse, entire or dentate, with short regular teeth, distinctly free to the comparatively short base, those near the top of the stem 3 to 5 mm. long, the largest 10 to 15 mm. long, 8 to 10 mm. wide. Venation distinct; three to four veins leave the base of each leaflet, branch and spread rapidly; the outer ones curve decidedly and meet the border a little above the middle of the leaflet. Veins numerous, counting 25 to 28 to the leaflet.

The distinguishing features of this species are the obovate form, the lightly notched border which extends well around the sides, and the numerous veins arising from about three or four basal veins, spreading rapidly and meeting the border about the middle of the leaflet. The species is very abundant and has been recognized in all the localities in the Wellington from which collections have been made. The leaflets, although varying much in size on different parts of the plant, are constant in shape and easily recognized. The plant was evidently tall and slender. In some layers the calcareous stone is completely filled with this species. Some of the stems reach a size of 6 mm. across, and continue for a distance of 20 cm. without any appreciable reduction in size. The leaflets appear to have been deciduous from the older part of the stem, as they are found attached near the apex only. The branches seem to have arisen one only at the node, and are attached as seen in the accompanying text figure, partly below but mostly above the diaphragm separating the internodes. *S. obovatum* differs from *S. fontaineanum* Miller (*S. latifolium* Fontaine and White) in the distinct obovate form of the leaflets and the more rapid spreading of the veins, which reach the lateral borders sooner. *S. fontaineanum* is described as having leaflets united laterally at the base, the lateral



Stem of Sphenophyllum obovatum.

margins nearly straight. From *S. thonii* the species here described is separated by its smaller size, ovate form, and absence of laceration of the leaflets.

Formation and locality: Wellington shales, Banner City, Dickinson county; Chase formation, Washington.

Sphenophyllum sp. Pl. LXI, figs. 19, 20.

An aparently undescribed species of *Sphenophyllum* is present in the collections from the Permian. The leaflets are unusually large, 24 mm. long and 9 or 10 mm. wide. They slope very gradually from a narrow base to a broad, obtusely rounded, dentate or entire apex. The apex is sometimes truncate or even very slightly emarginate at the center. The leaflets are clearly distinct at the base and are separated from each other by a space as wide or wider than the width of the base. The whorl consisted apparently of six leaflets. The veins are very fine and numerous. Two or possibly three slender veins leave the narrow base, dichotomize four or five times at a very narrow angle, and spreading only slightly fill the apex, counting around the border about 30 to 35. This form is separated from *S. obovatum*, with which it is associated, by the following characters: Veins finer, more numerous, and the angle between the dichotomy more acute; leaves much longer, but scarcely broader, base much more slender and more prolonged. Among the large number of specimens of *S. obovatum* found none seem to be intermediate between that species and the form here described.

Formation and locality: Wellington shales, Banner City, Dickinson county.

Sigillaria sp.

The genus *Sigillaria* occurs sparingly in the Wellington, although a number of leaves have been obtained. These are well preserved. From the upper side the midvein shows as a deep depression. The lamina arches from the midrib to the border. A few imperfectly preserved *Sigillaria* stems with distant leaf scars have been obtained. These are preserved in a sandy or calcareous matrix and are decorticated. Some specimens have been found also in the Wreford limestone, six miles west of Reece.

GYMNOSPERMS.

CORDAITALES.

CORDAITACEÆ.

Cordaites UNGER.

Cordaites sp. Pl. LXII, figs. 5, 6.

The genus *Cordaites* is represented by a species having long, slender leaves, 7 to 11 mm. broad at the half-clasping base, from which they gradually widen to 1½ to 2 cm. or more. The striæ are fine, broken, strong and weak alternating.

Formation and locality: Wellington shales, Banner City, Dickinson county, and the Wreford limestone, six miles west of Reece.

Cordaianthus ? sexpartitus sp. nov. Pl. LXII, figs. 11-13.

This small fossil, occurring abundantly, but always detached, consists of about six leaflets, 5 or 6 mm. long, all of equal length and attached at the same level, free to the base, traversed from base to apex by thin striæ. In having its scales attached at a common level this fossil differs from typical specimens of *Cordaianthus*, the male flowers of which are arranged in a small imbricated cone subtended by a bract. The plant described by Lesquereux (Coal Flora, p. 537, pl. 76, figs. 4 and 4*a*) as *Cordaianthus simplex* appears from the figure to have the scales united at a common level as in the plant from the Permian. The reference of this species to *Cordaianthus* is doubtful.

Formation and locality: Wellington shales, Banner City, Dickinson county.

Carpolithes sp. Pl. LXII, fig. 10.

The small seeds referred to this genus occur in considerable abundance and in association with the fossil described as *Cordaianthus* (?) *sexpartitus*. They are of a flatish, oblong shape, being about twice as broad as thick. The surface appears to have been covered by a very thin coating and is finely striated.

Formation and locality: Wellington shales, Banner City, Dickinson county, and the Wreford limestone, six miles west of Reece.

Rhabdocarpos GOEP. AND BERGER.

Rhabdocarpos sp. Pl. LXII, figs. 7, 8.

These seeds are 6 to 7 mm. long, 3 or 4 mm. wide, marked by numerous longitudinal striæ, and usually bordered by a thin layer representing a thin fleshy covering. One of the seeds has retained its attachment to a branch, which is 1½ cm. wide and has a roughly striated exterior.

Formation and locality: Wellington shales, Banner City, Dickinson county, and the Wreford limestone, six miles west of Reece.

Cardiocarpon sp. Pl. LXIII, fig. 6.

A few seeds of a species of this genus have been found. They are thin, broader than long. The apex acutely pointed; the nucleus indistinct.

Formation and locality: Wellington shales, Banner City, Dickinson county, and the Wreford limestone, six miles west of Reece.

CONIFERÆ.

Walchia STERNBERG.

Walchia pinniformis (Schloth.) Sternberg. Pl. LXVI, figs. 1, 2.

A species of *Walchia*, apparently *W. pinniformis*, occurs abundantly in the Wreford limestone. The locality from which the specimens were obtained is in the railroad cut six miles west of Reece. The plants are found at this locality on sandy shales between the layers of limestone. Among the small list of plants obtained here this species was found to be the most abundant. The genus has not been definitely recognized among the plants from the Wellington, although some small branches from this formation are referred doubtfully to *Walchia*.

Baiera sp.

Some specimens from the Wreford limestone are referred doubtfully to the genus *Baiera*. The leaves are divided in a manner analogous to *B. digitata* (Brongn.) Heer. The divisions are, however, very much broader than are those of *B. digitata*.

Aspidiopsis coniferoides Potonie. Pl. LXVI, fig. 4.

Potonié has described from the Permian of Thuringen, under the name of *Aspidiopsis coniferoides*, a decorticated

coniferous stem. A similar fossil occurs in the Permian of Kansas. The scars on the decorticated surface are long, slender, placed as a rule alternately. The Kansas specimen resembles the variety *A. coniferoides minor* rather closely.

Formation and locality: Wellington shales, Banner City, Dickinson county.

Genus undetermined.

An undetermined plant is found in some abundance in the Fort Riley limestone at Marysville. The plant is possibly a conifer, although apparently unlike any described conifer. Occasionally the bushy top presents a resemblance to *Gomphostrobus* as seen in some of Potonie's figures (Flora des Roth. von Thuringen). The stem part of the plant has longer appendages, which in some cases resemble rootlets. The collection of Mrs. Joseph Savage, of Lawrence, contains a specimen of this plant, reported to have been collected at Winfield.

Formation and locality: Fort Riley limestone, Marysville.

Geological Relation of the Fossil Plants of the Upper Paleozoic of Kansas.

By far the greater number of species collected from the Upper Paleozoic of Kansas have been obtained from the three following formations: The Cherokee shales, the Douglas formation, and the Wellington shales. The floras of these three formations, while overlapping somewhat, are largely distinct. The flora of the Douglas formation is largely different specifically from that of the Cherokee shales; the flora of the Wellington shales is almost entirely different from that of the Douglas formation; while between the Cherokee and Wellington no common species have been recognized.

FLORA OF THE CHEROKEE SHALES.

The flora of the Cherokee shales as developed at the coal-mines at Lansing is closely similar to the flora of the Cherokee shales in the vicinity of Clinton, Mo., not only in the number of identical species but in the facies of the flora as a whole. Of the species found at Lansing, about one-half have also been found at Clinton, Mo. The relation to the Mazon creek flora appears to be almost equally close, about one-third of the Lansing species being found also at Mazon creek. As compared with the English Coal Measures, the species are almost equally divided between the Middle and the Upper Coal Measures,

margins nearly straight. From *S. thonii* the species here described is separated by its smaller size, ovate form, and absence of laceration of the leaflets.

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Lawrence shales. More than two-thirds of the Wellington species are either identical with or most closely related to species or genera characteristic of the European Permian. The points which seem to have the most importance as bearing on the correlation of the Wellington are the following: (1) The complete absence of species in any way confined to or distinctive of the Coal Measures. (2) The comparatively small number of species originating as early as Upper Coal Measures time. (3) The presence of a few species common to and characteristic of the Permian of Europe. (4) The close relation of the new forms to species characteristic of the European Permian. (5) The distinctly Permian facies of the flora as a whole and its marked advance over the flora of the Upper Coal Measures.

The advance in the flora consists in the number of species and abundance of individuals of callipterid and tæniopterid ferns and of the new genus *Glenopteris*, which appears to be related on the one hand to callipterid ferns of Permian types, and on the other to the Triassic genera *Cycadopteris* and *Lomatopteris*.

The evidence derived from the fossil plants, seems to assure the reference of the Wellington to the true Permian in the European sense.

The flora of the formations intervening between the Douglas formation and the Wellington shales is much less satisfactorily known. A good deal of interest is attached to the discovery of plants in the Wreford limestone, especially as this formation has been recently regarded as the base of the Permian in Kansas. Nine species have been obtained from this locality, as follows: *Baiera* sp., *Callipteris conferta, Callipteris* sp., *Cardiocarpon* sp., *Carpolithes* sp., *Cordaites* sp., *Rhabdocarpos* sp., *Sigillaria* sp., *Walchia pinniformis*. The collection obtained from this formation is small and comes from a single locality near Reece, Kan. The association of the flora so far as obtained is with the Wellington rather than with Coal Measures flora. The presence of *Walchia* in abundance, and of callipterid ferns, along with the small species of seeds common to the Wellington, together with the absence, so far as yet noted, of all of the common Coal Measures species, gives the flora of the Wreford, as developed at Reece, a distinctive Permian facies.

Coal Measures species, although rare in the collection obtained from the Wreford limestone at the Reece locality, recur

while only a few of the Lansing species occur in the Lower Coal Measures as used in English literature. The general appearance of the flora as a whole is similar to the Middle rather than to the Upper Coal Measures of England, a result in agreement with White's correlation of the Clinton flora with the English Middle Coal Measures. The proportion of Upper Coal Measure species, however, is greater at the Lansing than at the Clinton locality. As compared with the Westphalian of Europe, the Lansing flora seems to find its closest resemblance to the middle and upper zones of the Valenciennes basin correlated by Zeiller and by Kidston with the English Middle beds and transitional to the Upper Coal Measures respectively.

FLORA OF THE DOUGLAS FORMATION.

As compared with European Coal Measures the flora of the Douglas formation presents a close resemblance to that of the Commentry coal-fields of France, the Stephanian, or distinctly Upper Coal Measures. Among the species of comparatively restricted range and diagnostic value common to the two terranes are the following: *Odontopteris genuina, O. minor, Pecopteris candolliana, Alethopteris grandini,* and *Daubreeia pateræformis.*

The change of flora from the Cherokee shales to the Douglas formation is decidedly marked. Hardly more than a fifth of the species collected have continued from the Cherokee into the Le Roy and Lawrence shales. Two of these, *Neuropteris scheuchzeri* and *N. ovata,* are represented in the Douglas formation by forms which should perhaps be considered as distinct varieties. The advance of the Douglas flora over that of the Cherokee shales is indicated by a greater development of odontopterid and pecopterid ferns. The flora of the intervening formations is very incompletely known. The two localities from which small collections have been made, Thayer in the Chanute shales, and Kansas City, near the base of the Bethany Falls limestone, both have floras resembling the Douglas flora more than the Cherokee flora.

THE FLORA OF THE WELLINGTON SHALES.

The flora of the Wellington differs *in toto,* so far as species are concerned, from that of the Cherokee shales, and contains only a small proportion of species found in the Douglas formation. Of the species listed from the Wellington only a few have been positively identified with forms found in the Le Roy and

Lawrence shales. More than two-thirds of the Wellington species are either identical with or most closely related to species or genera characteristic of the European Permian. The points which seem to have the most importance as bearing on the correlation of the Wellington are the following: (1) The complete absence of species in any way confined to or distinctive of the Coal Measures. (2) The comparatively small number of species originating as early as Upper Coal Measures time. (3) The presence of a few species common to and characteristic of the Permian of Europe. (4) The close relation of the new forms to species characteristic of the European Permian. (5) The distinctly Permian facies of the flora as a whole and its marked advance over the flora of the Upper Coal Measures.

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Coal Measures species, although rare in the collection obtained from the Wreford limestone at the Reece locality, recur

in some abundance in the horizon at Washington, regarded by Beede as near the top of the Chase formation. The species obtained from the Washington locality are listed below.

LISTS OF SPECIES BY FORMATIONS.

Lansing shales, Cherokee formation:

Eremopteris solida.
Eremopteris missouriensis.
Pseudopecopteris obtusiloba.
Pseudopecopteris squamosa.
Mariopteris occidentalis.
Pecopteris vestita.
Pecopteris unita.
Neuropteris clarksoni.
Sphenopteris pinnatifida.
Neuropteris vermicularis.
Neuropteris rarinervis.
Neuropteris ovata.
Neuropteris scheuchzeri.
Neuropteris missouriensis.
Neuropteris coriacea.
Neuropteris caudata.
Neuropteris gilmani.
Linopteris obliqua.
Callipteridium sullivantii.
Alethopteris serlii.
Alethopteris serlii missouriensis.
Sphenophyllum cuneifolium.
Sphenophyllum majus.
Calamites suckowii.
Asterophyllites equisetiformis.
Annullaria sphenophylloides.
Annullaria stellata.
Lepidodendron scutatum.
Lepidodendron clypeatum (?)
Lepidocystis sp.
Macrostachia infundibuliformis.
Sigillaria sp.
Trigonocarpum schultzianum.
Cordianthus ovatus.
Spiropteris.
Excipulites sp.
Rhabdocorpos cf. multistriatus.
Lepidodendron sp.

In addition to the list given above Mr. David White has recorded (Bull. 211, U. S. G. S., p. 110) the presence of the following species in the Cherokee shales at Lansing, Kan.:

Pseudopecopteris pluckeneti.
Sphenopteris denticulata.
Sphenopteris sp.
Pecopteris squamosa.
Pecopteris villosa?
Pecopteris cf. polymorpha?
Alethopteris sp.
Odontopteris papilionacea.
Neuropteris sp.
Neuropteris hastata.
Neuropteris carceraria.
Plintheotheca angularis.
Calamostachys brevifolia?
Sphenophyllum emarginatum var. minor.
Lepidostrobus cultriformis.
Cordaicarpon cinctum.
Rhabdocarpos mammilatus.

The Bethany Falls limestone at Kansas City, Kan., Pottawatomie formation:

Neuropteris lindahli.
Neuropteris hastata.
Cardiocarpon branneri.
Cordaites cf. communis.
Sigillaria sp. (leaves).
Cordianthus sp.

Mr. White lists from this locality also *Trigonocarpum adamsii?*

The Chanute shales, Pottawatomie formation:

Pseudopecopteris pluckenetii.
Sphenopteris pinnatifida.
Aloiopteris winslovii.
Pecopteris arborescens.
Neuropteris ovata.
Neuropteris scheuchzeri.
Asterophyllites equisetiformis.
Annullaria stellata.
Excipulites neesii.
Sphenopteris cunifolium.

Mr. White records the following additional species from Thayer (Bull. No. 211, U. S. Geol. Surv.):

Mariopteris cordato-ovata.
Alethopteris cf. virginiata.
Alethopteris grandini.
Odontopteris osmundæformis.
Odontopteris reichiana.
Neuropteris plicata.
Sphenophyllum oblongifolium.
Knorria compacta.
Sigillaria camptotænia.
Sigillaria rectostriata.

Douglas formation, Le Roy and Lawrence shales:

Pseudopecopteris cf. dimorpha.
Pseudopecopteris pluckenetii.
Mariopteris obtusiloba.
Sphenopteris cf. biturica.
Sphenopteris pinnatifida.
Sphenopteris sp.
Aloiopteris aquatica.
Aloiopteris winslovii.
Pecopteris candolliana.
Pecopteris arborescens.
Pecopteris cf. miltoni.
Pecopteris unita.
Oligocarpia kansasensis.
Oligocarpia gutbieri.
Aphlebia.
Neuropteris rogersi.
Neuropteris ovata.
Neuropteris scheuchzeri.
Neuropteris desorii.
Odontopteris genuina.
Odontopteris anomala.
Odontopteris excelsa.
Odontopteris minor.
Alethopteris grandini.
Callipteridium sp.
Callipteridium sp.
Sigillaria brardii.
Sigillaria brardii coriacea.
Sigillaria camptotænia.
Sigillaria sp.
Sigillaria sp.
Sigillariostrobus sp.
Calamites ramosus.
Calamites cistii.
Calamites suckowii.
Asterophyllites equisetiformis.
Annullaria sphenophylloides intermedia.
Annullaria stellata.
Sphenophyllum emarginatum.
Sphenophyllum cuneifolium.
Cordaites cummunis.
Cordianthus ovatus.
Trigonocarpum schultzianum.
Rhadocarpos emarginatus.
Cardiocarpon sp.
Daubreeia pateræformis.
Genus undt.
Hysterites sp.
Excipullites neesii.
Trigonocarpum sp.
Sternbergia.

Mr. White lists the following additional species from the Douglas formation (Bull. No. 211, U. S. Geol. Surv., p. 113, 1903):

Pecopteris cf. integra.
Pecopteris cf. hemiteloides.
Pecopteris cf. polymorpha.
Odontopteris ? sp.
Aphlebia filiformis.
Aphlebia accuminata.
Neuropteris hastata.
Calamites cannæformis.
Calamodendron cruciatum.
Bruckmannia tuberculata.
Sphenopyllum oblongifolium.
Sphenopyllum verticillatum.
Bothrodendron ? n. sp.
Sigillaria sucpecta.
Sigillaria laurenciana.
Sigillariastrobus quadranglaris
Sigillariastrobus clavatus.
Doleropteris pennsylvanica.
Rhabdocarpos coronatus.
Rhabdocarpos sulcatus.
Rhabdocarpos multistriatus.
Trigonocarpum starkianum.

Shawnee formation, Scranton shales:

Pecopteris arborescens.
Pecopteris cyathea.
Neuropteris ovata.
Neuropteris scheuchzeri.
Odontopteris excelsa.
Alethopteris grandini.
Sigillaria brardii.
Callamites suckowii.
Asterophyllites equisetiformis.
Annullaria sphenophylloides intermedia.
Cordianthus ovatus.

Mr. David White lists the following from the Scranton (Severy) shales (Bull. No. 211, U. S. Geol. Surv., p. 114, 1903):

Caulerpites n. sp. Lx.
Odontopteris osmundæformis (Schloth).
Lesleya microphylla Lx.
Calamites ramosus.
Cordaites squammiferus Lx.
Cardocarpon kansasiense Lx.
Cardocarpon ellipticum (Sternb.) Lx.
Rhadbocarpos amygdalæformis.
Trigonocarpon starkianum Lx.
Trigonocarpon kansaseanum Lx.
Carpolithes granularis.

The Elmdale shales, Wabaunsee formation:

Neuropteris scheuchzeri.
Sigillaria sp.
Cordiates sp.
Cardiocarpon sp.
Daubreeia pateræformis.
Pinnularia.
Callipteris sp. nov.
Callipteris conferta.

Mr. David White lists the following from the Elmdale shales at Onaga (Bull. No. 211, U. S. Geol. Surv., p. 115, 1903):

Pecopteris newberriana.
Pecopteris hemiteloides.
Pecopteris oreopteridia.
Pecopteris cf. polymorpha.
Odontopteris brardii.
Odontopteris moorii.
Neuropteris plicata.
Neuropteris auriculata.
Asterophyllites equisetiformis.
Annularia stellata.
Radicites capillaceus.

The Wreford limestone, Chase formation:

Callipteris conferta.
Callipteris sp.
Sigillaria sp.
Cordaites sp.
Baiera sp.
Carpolithes sp.
Rhabdocarpos sp.
Cardiocarpon sp.
Walchia pinniformis.
Callipteris sp.

Winfield limestone, Chase formation:

Pseudopecopteris sp.
Pecopteris arborescens.
Pecopteris sp.
Aphlebia sp.
Neuropteris ovata.
Neuropteris scheuchzeri.
Neuropteris desorii.
Neuropteris cf. permiana.
Odontopteris excelsa.
Odontopteris reichiana.
Alethopteris sp.
Callipteris conferta.
Callipteris sp.
Calamites ? sp.
Sphenophyllum obovatum.
Cordaites sp.
Carpolithes sp.
Rhabdocarpos sp.

The Wellington shales, Sumner stage:

Pecopteris arborescens.
Pecopteris cf. hemiteloides.
Pecopteris cyathea.
Neuropteris permiana.
Callipteris conferta.
Callipteris whitii.
Callipteris elongata.
Callipteris cf. bergeroni.
Callipteris sp.
Glenopteris splendens.
Glenopteris sterlingi.
Glenopteris simplex.
Glenopteris lineata.
Glenopteris lobata.
Odontopteris reichiana.
Odontopteris minor.
Tæniopteris coriacea.
T. coriacea linearis.
Tæniopteris newberriana.
Sphenophyllum obovatum.
Sphenophyllum sp.
Carpolithes sp.
Rhabdocarpos sp.
Cardiocarpon sp.
Cordaites sp.
Cordianthus ? sexipartitus.
Walchia pinniformis.
Aphlebia lacineata.
Aphlebia sp.
Sigillaria sp.
Calamites sp.
Aspidiopsis coniferoides.
Genus undt.

EXPLANATION OF PLATES.

PLATE XLIV.

FIG. 1.—*Pseudopecopteris pluckenetii* (Schloth.) Lesqx. The basal part of a small pinna, showing the winged rachis and ovate pinnules, with a few thin veins. From the Chanute shales. No. 550, University of Kansas collection. Three times natural size.

FIGS. 2, 3.—*Pseudopecopteris cf. dimorpha.* Pinnules showing venation. From the Lawrence shales, Twinmound. No. 590, University of Kansas Collection. Natural size.

FIG. 4.—*Mariopteris occidentalis* D. W. A single pinnule, showing venation. From the Cherokee shales, Lansing. No. 401, University of Kansas collection. Three times natural size.

FIG. 5.—*Sphenopteris pinatifida* (Lesqx.) D. W. Pinnæ and pinnules of this species, showing typical form. From the Le Roy shales at Blue Mound. No. 906, University of Kansas collection. Twice natural size.

FIGS. 6-8.—*Sphenopteris cf. biturica* Zeiller. Normal form of pinnæ and pinnules of this species. From the Le Roy shales at the Haverkampf farm. No. 926, University of Kansas collection. Twice natural size.

FIGS. 9, 10.—*Sphenopteris* sp. A delicate *Sphenopteris* with thin frond and flexuous veins forking once at a wide angle. From the Le Roy shales at Blue Mound. No. 790, University of Kansas collection. Figure 9, natural size; figure 10, three times natural size.

FIG. 11.—*Eremopteris solida* (Lesqx.) D. W. A small pinna, showing the bifid pinnules marked with indistinct striæ. From the Cherokee shales at Lansing, Kan. No. 100, University of Kansas collection. Twice natural size.

FIG 12.—*Eremopteris missouriensis* Lesqx. A small pinna, showing the narrow pinnules. From the Cherokee shales, Lansing. No. 125, University of Kansas collection. Twice natural size.

FIG. 13.—*Aloiopteris winslovii* D. W. One of the long, slender pinnules of this species. From the Le Roy shales. No. 1003, University of Kansas collection. Twice natural size.

FIG. 14.—*Aloiopteris winslovii* D. W. Enlarged to show detail of venation. From the Chanute shales, Thayer. No. 1003, University of Kansas collection. Twice natural size.

FIG. 15.—*Aloiopteris winslovii* D. W. Details of a pinnule from the Chanute shales, Thayer. No. 1000, University of Kansas collection. Twice natural size.

FIG. 16.—*Aloiopteris winslovii* D. W. Rachis with *Aphlebia* pinnule. From the Chanute shales, Thayer. No. 1000, University of Kansas collection. Natural size.

FIG. 17.—*Aloiopteris winslovii* D. W. Apex of a long pinnule with flexuous veins. From the Lawrence shales at Twinmound. No. 990, University of Kansas collection. Twice natural size.

PLATE XLV.

FIG. 1.—*Pecopteris unita* Brongn. Part of a pinna, with pinnules connate to above the middle. From the Le Roy shales. No. 1454, University of Kansas collection. Natural size.

FIG. 2.—*Pecopteris unita* Brongn. Enlarged pinnule. Twice natural size.

FIG. 3.—*Pecopteris arborescens* (Schloth.) Brongn. A fertile pinnule, with the impressions of the large sporangia, about four to the synangium and grouped around a central point of attachment. From the Lawrence shales at Twinmound. No. 1228, University of Kansas collection. Twice natural size.

FIGS. 4, 5.—*Pecopteris arborescens* (Schloth.) Brongn. Single sterile pinnules, showing the simple veins. From the Lawrence shales at Twinmound and the Le Roy shales at Blue Mound. Nos. 1229 and 1230, University of Kansas collection. Twice natural size.

FIG. 6.—*Pecopteris candolleana* Brongn. Two of the pinnules, showing characteristic form and venation. From the Lawrence shales at Twinmound. No. 1301, University of Kansas collection. Three times natural size.

FIGS. 7, 8.—*Pecopteris candolliana* Brongn. Pinnules referred doubtfully to this species. From the Le Roy shales at the Haverkampf farm. No. 1302, University of Kansas collection. Three times natural size.

FIG. 9.—*Pecopteris candolliana* Brongn. Small pinnule referred doubtfully to this species. From the Le Roy shales at the Haverkampf farm. No. 1325, University of Kansas collection. Twice natural size.

FIG. 10.—*Pecopteris vestita* Lesqx. Two of the pinnules, with thick, scaly epidermis characteristic of this species. From the Cherokee shales, Lansing. No. 1277, University of Kansas collection. Twice natural size.

FIG. 11.—Same species. The epidermis of the pinnules removed by acid to show the venation. Twice natural size.

FIGS. 12, 13.—Same species. Pinnules with epidermis partly removed. Twice natural size.

FIG. 14.—*Oligocarpia gutbieri.* Fertile pinnules. From the Lawrence shales at Twinmound. No. 1213, University of Kansas collection. Twice natural size.

FIG. 15.—*Pecopteris cf. miltoni* Lesqx. From the Lawrence shales, Twinmound. Enlarged.

FIGS. 16-19.—*Oligocarpia kansasensis* sp. nov. Sterile and fertile pinnules. From the Lawrence shales at Twinmound. Nos. 1100 and 1101, University of Kansas collection. Twice natural size.

FIG. 20.—*Mariopteris obtusiloba* D. W. var. From the Le Roy shales. No. 1583, University of Kansas collection. Enlarged.

FIG. 21.—*Odontopteris minor.* From the Le Roy shales at the Haverkampf farm. No. 650, University of Kansas collection. Twice natural size.

FIG. 22.—*Callipteridium* sp. From the Le Roy shales at the Haverkampf farm. Natural size.

PLATE XLVI.

FIG. 1.—*Mariopteris obtusiloba* D. W. var. Terminal part of a pinna. University of Kansas collection. Natural size.

FIG. 2.—Same species. The basal part of a typical pinna. University of Kansas collection. Natural size.

FIG. 3.—Same species. A pinna with broad pinnules. No. 1583, University of Kansas collection. One and one-half times natural size.

FIG. 4.—Same species. Apex of one of the obtuse pinnules, showing venation. University of Kansas collection. Three times natural size.

FIG. 5.—Same species. One of the pinnæ, with very long pinnules and winged rachis. No. 576, University of Kansas collection. Figures 1 to 5 from the Le Roy shales.

FIG. 6.—*Odontopteris anomala* sp. nov. A large pinna, showing the unsymmetrical development. The rachis is bordered on one side by a broad lamina supplied by numerous veins arising from the rachis, while on the opposite side large, elongate pinnules are attached. The venation is extremely irregular and wavy, the veins often running together for some distance, then separating. No. 631, University of Kansas collection. From the Le Roy shales at the Haverkampf farm. Natural size.

FIG. 7.—Details of venation, taken from specimen illustrated by figure 6. Twice natural size.

FIG. 8.—*Neuropteris scheuchzeri* Hoffm. with *Hysterites*. No. 5690, University of Kansas collection. From the Le Roy shales.

PLATE XLVII.

FIGS. 1, 2.—*Rhabdocarpos cf. emarginatus*. From the Le Roy shales. Nos. 5498 and 5496, University of Kansas collection.

FIG. 3.—*Sigillaria*. A slender leaf with upward curve at the apex.

FIG. 4.—The apical part of a very long leaf with straight obtuse apex.

FIG. 5.—A section of a very large leaf with finely but distinctly serrate edges.

FIG. 6.—From the same. Figures 3 to 6 from the Le Roy shales at Blue Mound. Figures 1 to 5 natural size; figure 6 twice natural size.

FIGS. 7, 8.—*Sphenophyllum emarginatum* Brongn. From the Le Roy shales at the Haverkampf farm. No. 4012, University of Kansas collection.

FIG. 9.—Middle part of a very large *Sigillaria* leaf. From the Le Roy shales at Blue Mound. Natural size.

FIG. 10.—*Cordianthus* sp. From near the base of the Bethany Falls limestone at Kansas City, Kan. No. 5533, University of Kansas collection. Twice natural size.

FIG. 11.—*Sigillaria* sp. Enlarged leaf-scar. From the Cherokee shales at Lansing. No. 4340, University of Kansas collection.

PLATE XLVIII.

FIG. 1.—*Neuropteris rogersi* Lesqx. Apical part of a large pinnule, showing the upward curvature of the veins at the border, the lobate margin, and the thickened area at the apex. From the Lawrence shales at Twinmound. Twice natural size.

FIG. 2.—*Neuropteris vermicularis* Lesqx. The terminal part of a pinna, illustrating the very large spatulate terminal pinnule. From the Cherokee shales at Lansing. No. 2101, University of Kansas collection. Natural size.

FIG. 3.—Detail of venation of same. Three times natural size.

FIG. 4.—*Neuropteris missouriensis* Lesqx. Illustrating the broad obtuse pinnules, rounded both above and below the base, and with numerous veins. From the Cherokee shales at Lansing. No. 3076, University of Kansas collection. Twice natural size.

FIG. 5.—*Neuropteris rarinervis* Bunb. A pinnule of the typical form, and with thick distant veins forking at a wide angle. From the Cherokee shales at Lansing. No. 3001, University of Kansas collection. Three times natural size.

FIG. 6.—*Neuropteris hastata* D. W. The very long acuminate apex of one of the pinnules. From the Bethany Falls limestone at Kansas City, Kan. No. 2081, University of Kansas collection. Natural size.

FIGS. 7, 8.—*Neuropteris lindahli* D. W. Typical long pinnules with cordate bases. From the Bethany Falls limestone at Kansas City, Kan. No. 2076, University of Kansas collection. Twice natural size.

FIG. 9.—*Neuropteris ovata* Hoffm. Large pinnules with numerous veins. From the Le Roy shales at Blue Mound. No. 2156, University of Kansas collection. Three times natural size.

FIG. 10.—*Linopteris obliqua* (Bund). From the Cherokee shales at Lansing. No. 6075, University of Kansas collection. Three times natural size.

FIG. 11.—*Neuropteris desorii* Lesqx. A large pinnule from the Lawrence shales at Twinmound. No. 606, University of Kansas collection. Three times natural size.

FIG. 12.—*Neuropteris rogersi* Lesqx. Veins at the border of the pinnule. From the Lawrence shales at Twinmound. Much enlarged.

FIG. 13.—*Mariopteris obtusiloba* D. W. var. Middle and basal pinnules of an ultimate pinna. From the Le Roy shales. No. 582, University of Kansas collection. Twice natural size.

PLATE XLIX.

FIG. 1.—*Odontopteris genuina* Grand Eury. Pinnules of the average size, showing the numerous veins forking near the borders. From the Le Roy shales at the Haverkampf farm, three miles southeast of Lawrence. No. 630, University of Kansas collection. Twice natural size.

FIG. 2.—*Mariopteris obtusiloba* D. W. var. Terminal part of a pinna with broad pinnules. From the Le Roy shales. No. 580, University of Kansas collection. Natural size.

FIG. 3.—*Alethopteris grandini* (Brongn.) Goep. A typical large pinnule. From the Le Roy shales. No. 1983, University of Kansas collection. Three times natural size.

FIG. 4.—Venation of same.

FIG. 5.—*Neuropteris hastata* D. W. From the Bethany Falls limestone at Kansas City, Kan. No. 2076, University of Kansas collection.

FIG. 6.—*Odontopteris genuina* Grand Eury. Ultimate pinnæ, showing the broad pinnules passing into a large terminal pinnule at the top. The basal pinnule on the lower side is deflexed and ovate. All are without midrib and supplied by many branched veins. From the Le Roy shales. No. 631, University of Kansas collection. Natural size.

FIG. 7.—*Odontopteris excellsa* sp. nov. Part of a large pinna, showing the very large pinnules with few veins. From the Le Roy shales. No. 626, University of Kansas collection. Natural size.

FIG. 8.—Same species. Two large pinnules, showing their broad obtuse form and distant veins. From the Le Roy shales at the Haverkampf farm. No. 626, University of Kansas collection. Natural size.

FIG. 9.—*Odontopteris excellsa* sp. nov. Part of a pinna, showing punctate rachis and distant venation, the veins arising from the rachis without a midrib. From the Lawrence shales at Twinmound. No. 625, University of Kansas collection. Natural size.

PLATE L.

FIGS. 1, 2.—*Callipteridium sullivantii* (Lesqx.) Weiss. From the Cherokee shales at Lansing. No. 1701, University of Kansas collection. Twice natural size.

FIGS. 3, 4.—*Callipteridium* sp. From the Lawrence shales. No. 1896, University of Kansas collection. Three times natural size.

FIG. 5.—*Alethopteris serlii* (Brongn.) Goep. From the Cherokee shales at Lansing. No. 1950, University of Kansas collection. Twice natural size.

FIG. 6.—*Neuropteris caudata* D. W.? From the Cherokee shales at Lansing. No. 2190, University of Kansas collection. Three times natural size.

FIG. 7.—*Neuropteris desorii* Lesqx. Ultimate pinnæ, with small pinnules becoming connate with the large terminal pinnule. From the Le Roy shales at the Haverkampf farm. No. 601, University of Kansas collection. Natural size.

FIG. 8.—Enlarged pinnule of same, from near the top of the pinna.

FIGS. 9, 10.—*Neuropteris desorii* Lesqx. Medium-sized pinnules. From the Le Roy shales at Oak Hill Cemetery, near Lawrence. No. 600, University of Kansas collection. Three times natural size.

FIG. 11.—*Neuropteris ovata* Hoffm. Pinnule, with pointed auricle. From the Lawrence shales at Twinmound. No. 2195, University of Kansas collection. Three times natural size.

PLATE LI.

FIG. 1.—*Alethopteris grandini* (Brongn.) Goep.? A fertile pinnule, referred with some doubt to this species. The venation is obscured. The sporangia seem to be arranged in rows from the midrib to the border, as in the case of the living genus *Danæa*, or the Coal Measures genus *Danæites*. From the Le Roy shales. No. 1986, University of Kansas collection. Three times natural size.

FIG. 2.—*Sigillaria* sp. A large species with thin, rough cortex and distant leaf-scars. The decorticated surface is very rough and marked with longitudinal striæ. The lateral cicatricules are very large and have a pitted surface. From the Le Roy shales at Blue Mound. No. 4316, University of Kansas collection. Natural size.

FIGS. 3, 4.—Basal part of a very slender lycopod leaf, showing the form of the scar to which it was attached. From the Lawrence shales, University Hill. No. 5502, University of Kansas collection. Natural size.

FIG. 5.—*Lepidodendron clypeatum* (?) Lesqx. From the Cherokee shales at Lansing. No. 5445, University of Kansas collection. Natural size.

FIG. 6.—*Sigillaria* sp. An area from the surface of a large trunk marked by longitudinal ribs, with a single row of scars on each rib. From the Cherokee shales at Lansing. No. 4340, University of Kansas collection. Natural size.

FIG. 7.—Genus undetermined. Thin, delicate leaves, with a clear, transparent lamina, traversed by a single vascular strand. The fronds are dichotomous and were of considerable length. They occur in abundance in the Le Roy shales at the Haverkampf farm. Nos. 5675 and 5677, University of Kansas collection. Natural size.

FIG. 8.—*Sigillaria brardii* Brongn. A small area from the trunk of a large tree, showing the form and arrangement of the leaf-scars. From the Le Roy shales at Blue Mound. No. 4391, University of Kansas collection. Natural size.

FIG. 9.—*Lepidodendron* sp. From the Cherokee shales at Lansing. No. 4450, University of Kansas collection. Natural size.

FIG. 10.—Genus undetermined. From the Le Roy shales. No. 5678, University of Kansas collection. Natural size.

FIG. 11.—*Cardiocarpon branneri* Fairchild and D. W. mns. An unusually well-preserved seed of this species. The seed is small, flat, the nucleus covered with fine hairs. From the Bethany Falls limestone at Kansas City, Kan. No. 5490, University of Kansas collection. Natural size.

FIGS. 12, 13.—*Cardiocarpon* sp. Seeds of a type very abundant in the Le Roy shales. No. 5493, University of Kansas collection. Natural size.

FIG. 14.—*Trigonocarpum* sp. From the Lawrence shales. No. 5489, University of Kansas collection. Natural size.

PLATE LII.

FIG. 1.—*Daubreeia.* Outer edge of the frond. This specimen shows very distinctly the pitting of the surface of the frond described in the text as possibly fructification. From the Elmdale at Onaga. No. 9682, United States National Museum, transmitted for study by Mr. David White. At the right of figure 1 is a well-preserved specimen of *Trigonocarpum schultzianum* from the Le Roy shales, Lawrence. University of Kansas collection.

FIG. 2.—*Alethopteris grandini*(?) at the left, and *Daubreeia pateræformis* at the right. *Alethopteris grandini* from the Scranton shales at Scranton. *Daubreeia* from the Elmdale formation at Onaga. No. 9667, United States National Museum, transmitted for study by Mr. David White.

PLATE LIII.

FIG. 1.—*Nueropteris rarinervis* Bunb. From the Cherokee shales, Lansing. No. 3001, University of Kansas collection. Natural size.

FIG. 2.—*Neuropteris ovata* Hoffm. From the Cherokee shales, Lansing. University of Kansas collection. Natural size.

FIG. 3.—*Oligocarpia kansasensis* Sellards. From the Lawrence shales, Twinmound. University of Kansas collection. Natural size.

FIG. 4.—*Sphenophyllum cuneifolium.* From the Lawrence shales, Twinmound. University of Kansas collection.

FIG. 5.—*Annullaria sphennophylloides.* From the Cherokee shales, Lansing. Natural size.

FIG. 6.—*Macrostachya infundibuliformis.* From the Cherokee shales, Lansing. University of Kansas collection.

PLATE LIV.

FIG. 1.—*Neuropteris desorii.* From the Le Roy shales at the Haverkampf farm, near Lawrence. Natural size.

FIG. 2.—*Pseudopecopteris obtusiloba.* From the Cherokee shales, Lansing. Natural size.

FIG. 3.—*Sphenopteris pinnatifida.* From the Lawrence shales at Twinmound. Natural size.

FIG. 4.—*Pseudopecopteris obtusiloba.* From the Cherokee shales, Lansing. Natural size.

PLATE LV.

FIG. 1.—*Alethopteris grandini.* From Le Roy shales, Blue Mound. Natural size.

FIG. 2.—*Mariopteris obtusiloba.* From the Le Roy shales, Haverkampf farm, near Lawrence. Natural size.

FIG. 3.—*Aphlebia* sp. From the Le Roy shales, Haverkampf farm, near Lawrence. Natural size.

FIG. 4.—*Daubreeia pateræformis.* From the Elmdale formation at Onaga. Natural size. Loaned, for illustration, from the National Museum.

PLATE LVI.

FIG. 1.—*Pseudopecopteris cf. dimorpha.* From the Lawrence shales at Twinmound. Natural size.

FIG. 2.—*Neuropteris rarinervis.* From the Cherokee shales at Lansing. Natural size.

FIG. 3.—*Lepidodendron scutatum.* From the Cherokee shales at Lansing. Natural size.

FIG. 4.—*Odontopteris anomala.* From the Le Roy shales at the Haverkampf farm, near Lawrence. Natural size.

FIG. 5.—*Daubreeia* (?) From the Le Roy shales, Blue Mound. Natural size.

FIG. 6.—*Neuropteris ovata.* From the Scranton shales at Scranton. Natural size.

FIG. 7.—*Alethopteris serlii missouriensis.* From the Cherokee shales at Lansing. Natural size.

FIG. 8.—*Neuropteris vermicularis.* From the Cherokee shales at Lansing. Natural size.

FIG. 9.—*Aphlebia* sp. Lawrence shales, Deer Creek. Natural size.

PLATE LVII.

FIG. 1.—*Sigillaria brardii.* From the Le Roy shales at Blue Mound. Natural size.

FIG. 2.—*Eremopteris solida*, and *Eremopteris missouriensis.* From the Cherokee shales at Lansing. Natural size.

FIG. 3.—*Sigillaria brardii.* From the Le Roy shales at Blue Mound. Natural size.

FIG. 4.—*Spehophyllum majus.* From the Cherokee shales at Lansing. Natural size.

PLATE LVIII.

FIG. 1.—*Daubreeia pateræformis.* From the Le Roy shales at Blue Mound. Natural size.

FIG. 2.—*Sphenopteris cf. biturica.* From the Le Roy shales at the Haverkampf farm, near Lawrence. Natural size.

FIG. 3.—*Trigonocarpum schultzianum.* From the Le Roy shales at the Haverkampf farm, near Lawrence. Enlarged.

FIG. 4.—*Neuropteris gilmani.* From the Cherokee shales at Lansing. Reduced.

PLATE LIX.

FIG. 1.—*Neuropteris rogersi.* From the Lawrence shales at Twinmound. Slightly enlarged.

FIG. 2.—*Cordaites communis.* From the Le Roy shales at the Haverkampf farm, near Lawrence. Reduced.

PLATE LX.

FIG. 1.—*Callipteridium sullivantii.* From the Cherokee shales, Lansing. Natural size.

FIG. 2.—*Alethopteris grandini.* From the Le Roy shales, Blue Mound. Slightly reduced.

FIG. 3.—*"Sternbergia."* From the Lawrence shales. About natural size.

PLATE LXI.

FIG. 1.—*Neuropteris permiana* sp. nov. One of the elongate pinnules with obtuse apex. From the Wellington shales. No. 5202, University of Kansas collection. Natural size.

FIG. 2.—*Pecopteris arborescens* (Schloth.) Brongn. From the Wellington shales. No. 5249, University of Kansas collection. Natural size.

FIG. 3.—*Pecopteris cf. cyathea* (Schloth.) Brongn. From the Wellington shales. University of Kansas collection. Twice natural size.

FIGS. 4-6.—*Pecopteris cf. hemitelioides* Brongn. From the Wellington formation. No. 536, University of Kansas collection.

FIG. 7.—*Callipteris cf. bergeroni* Zeiller. From the Wellington formation. No. 5323, University of Kansas collection. Natural size.

FIGS. 8-11.—*Callipteris whitii* sp. nov. Specimens illustrated by figures 8 and 9 are typical of the species. Nos. 5352, 5355, 5357, University of Kansas collection. Figures 8 to 10, twice natural size; figure 11, three times natural size.

FIGS. 12, 13.—*Callipteris conferta* Sternb. Nos. 5302, 5303, University of Kansas collection. Natural size.

FIG. 14.—*Callipteris* sp. University of Kansas collection. Natural size.

FIG. 15.—*Callipteris* sp. Part of a very large, coarse callipterid fern. No. 5317, University of Kansas collection. Natural size.

FIG. 16.—*Callipteris elongata* sp. nov. Pinnules showing venation. No. 5312, University of Kansas collection. Natural size.

FIG. 17.—*Sphenophyllum obovatum* sp. nov. A single whorl of leaves, showing four of the six leaflets. About three to four veins originate from the base of each leaflet. These divide, the lateral ones soon reaching the border. The obovate form of the leaflets is well shown in this specimen. The border is slightly notched. No. 5369, University of Kansas collection.

FIG. 18.—A single leaflet of same. Natural size.

FIG. 19.—*Sphenophyllum* sp. Three leaflets, showing long, slender form, almost entire edges, narrow bases. No. 5375, University of Kansas collection. Natural size.

FIG. 20.—Two leaflets from the same verticil. Twice natural size.

All from the Wellington shales near Banner City, Kan.

PLATE LXII.

FIGS. 1-4.—Leaves of *Sigillaria*. Nos. 5335, 5336, 5337, 5338, University of Kansas collection. Natural size.

FIGS. 5, 6.—*Cordaites* sp. Nos. 5290 and 5292, University of Kansas collection. Natural size.

FIG. 7.—*Rhabdocarpos sp.* A small seed attached directly to a roughly striated stem. Natural size.

FIG. 8.—A similar seed detached and with external envelope destroyed. No. 5345, University of Kansas collection. Three times natural size.

FIG. 9.—*Neuropteris permiana* sp. nov. No. 5200, University of Kansas collection.

FIG. 10.—*Carpolithes*. Very small seeds found in abundance three miles south of Banner City, Kan. Nos. 5267 and 5268, University of Kansas collection. Natural size.

FIGS. 11, 12.—*Cordianthus ? sexpartitus* sp. nov. Small bud-like plants, consisting of five, usually six, scales attached in a circle at the base. Nos. 5276 and 5277, University of Kansas collection. Natural size.

FIG. 13.—Same, with four of the scales spread apart. Three times natural size.

FIG. 14.—*Odontopteris reichiana*. No. 525, University of Kansas collection. Natural size.

FIG. 15.—Same species. No. 5256, University of Kansas collection. Natural size.

FIG. 16.—Same species. No. 5257, University of Kansas collection. Natural size.

FIG. 17.—*Odontopteris minor*. No. 5254, University of Kansas collection. Five times natural size.

All from the Wellington shales near Banner City, Kan.

PLATE LXIII.

FIG. 1.—*Neuropteris permiana* sp. nov. One of the very long pinnules, with nearly parallel sides and very strong rachis, and presenting much the appearance of a *Tæniopteris*. No. 5203, University of Kansas collection. Natural size.

FIG. 2.—Venation from figure 1. Twice natural size.

FIG. 3.—Same species. A very large basal or cyclopterid pinnule. No. 5204, University of Kansas collection. Natural size.

FIG. 4.—Same species. Part of a very large pinnule, attached to a strong, striated rachis by a short pedicel. No. 5205, University of Kansas collection. Natural size.

FIG. 5.—*Odontopteris reichiana* Gutbier. A part of the frond, showing its dichotomous character. The first pinnæ above the dichotomy on the inner side are reduced. No. 5251, University of Kansas collection. Natural size.

FIG. 6.—*Cardiocarpon* sp. No. 5330, University of Kansas collection.

FIG. 7.—*Callipteris* sp. Apex of pinna. No. 5319, University of Kansas collection. Natural size.

FIG. 8.—*Callipteris* sp. University of Kansas collection. Natural size.

FIG. 9.—*Callipteris conferta*. University of Kansas collection. Natural size.

All from the Wellington shales near Banner City, Kan.

PLATE LXIV.

FIG. 1.—*Cycadaceous plant?* Gn. sp. undetermined, and *Cordaites* sp. From Banner City. Natural size.

FIG. 2.—*Callipteris* sp. From Banner City. Natural size.

FIG. 3.—*Callipteris* sp. From Banner City. Natural size.

FIG. 4.—*Sphenophyllum obovatum.* From Banner City. Natural size.

FIG. 5.—*Callipteris conferta.* From Banner City. Natural size.

PLATE LXV.

FIG. 1.—*Callipteris bergeroni.* From Banner City. Natural size.

FIG. 2.—*Calamites* sp. From Banner City. Natural size.

PLATE LXVI.

FIGS. 1, 2.—*Walchia pinniformis.* From the Chase formation, six miles west of Reece. Natural size.

FIG. 3.—*Callipteris whitii.* From the Wellington shales, Banner City. Natural size.

FIG. 4.—*Aspidiopsis coniferoides.* From the Wellington shales, Banner City. Slightly reduced.

PLATE LXVII.

FIG. 1.—*Tæniopteris coriacea* Goep. From Banner City. No. 5022, University of Kansas collection. Natural size.

FIG. 2.—Same species. Specimen No. 5023. Natural size.

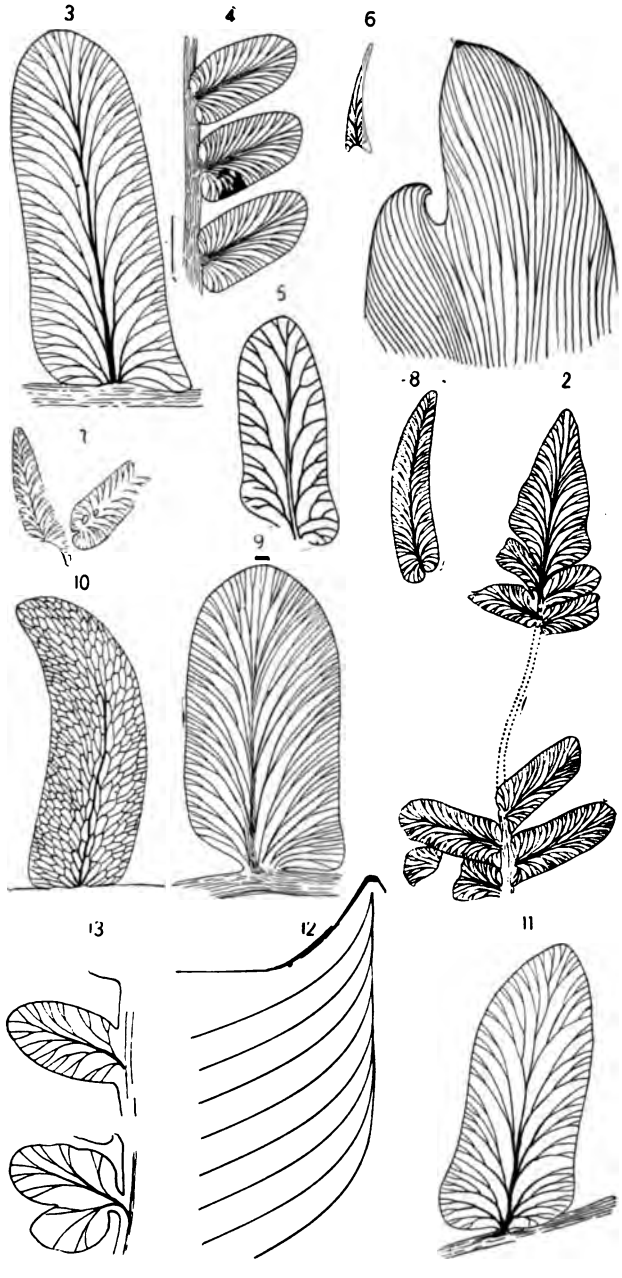
PLATE LXVIII.

FIG. 1.—*Tæniopteris coriacea* Goep. Specimen with scars on the rachis. From the Wellington formation, Banner City. No. 5002, University of Kansas collection. Natural size.

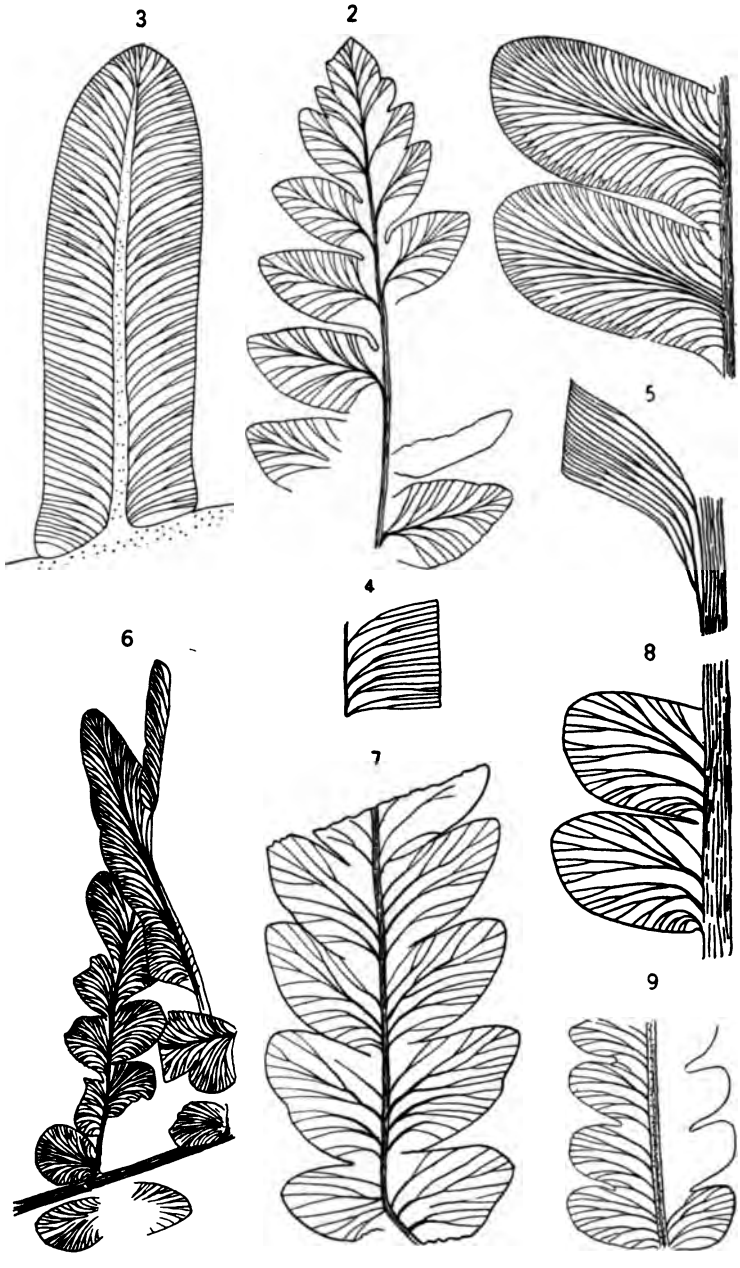
FIG. 2.—Same species, apex of frond. No. 5024, University of Kansas collection. Natural size.

FIG. 3.—*T. coriacea linearis.* From the Wellington formation, Banner City. No. 5004, University of Kansas collection. Natural size.

FIG. 4.—*T. coriacea linearis.* From the Wellington formation, Banner City. No. 5004, University of Kansas collection. Natural size.



KANSAS COAL MEASURES PLANTS.



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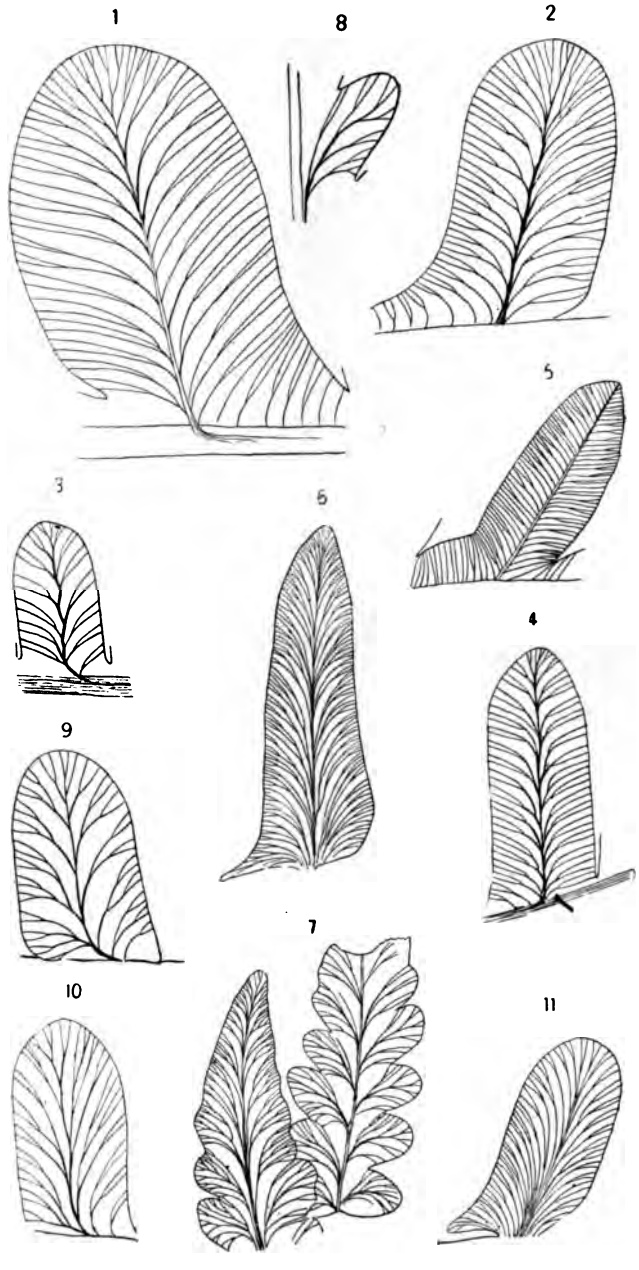

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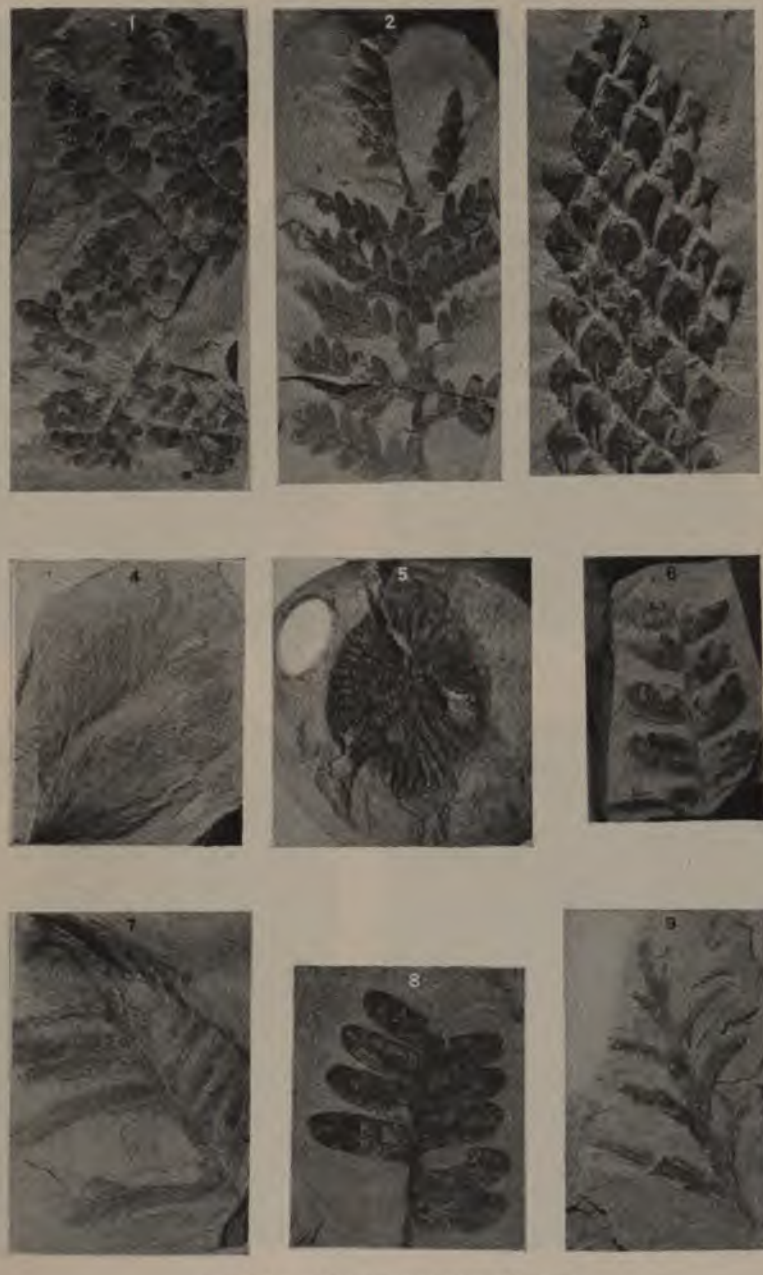

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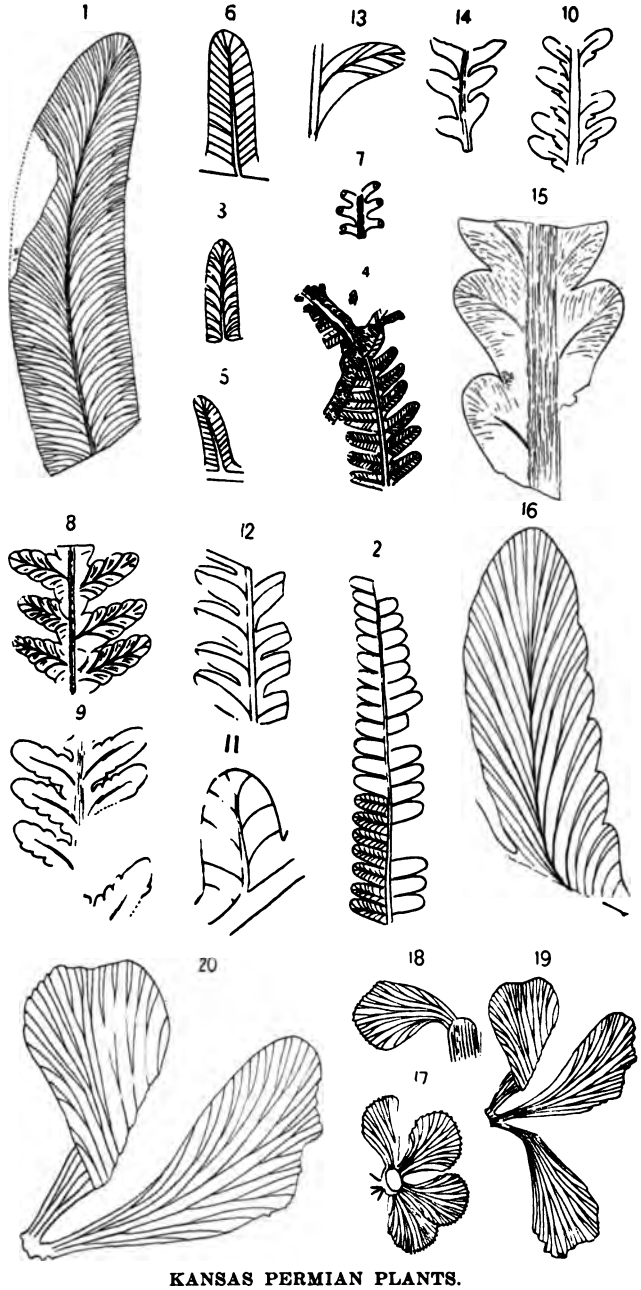
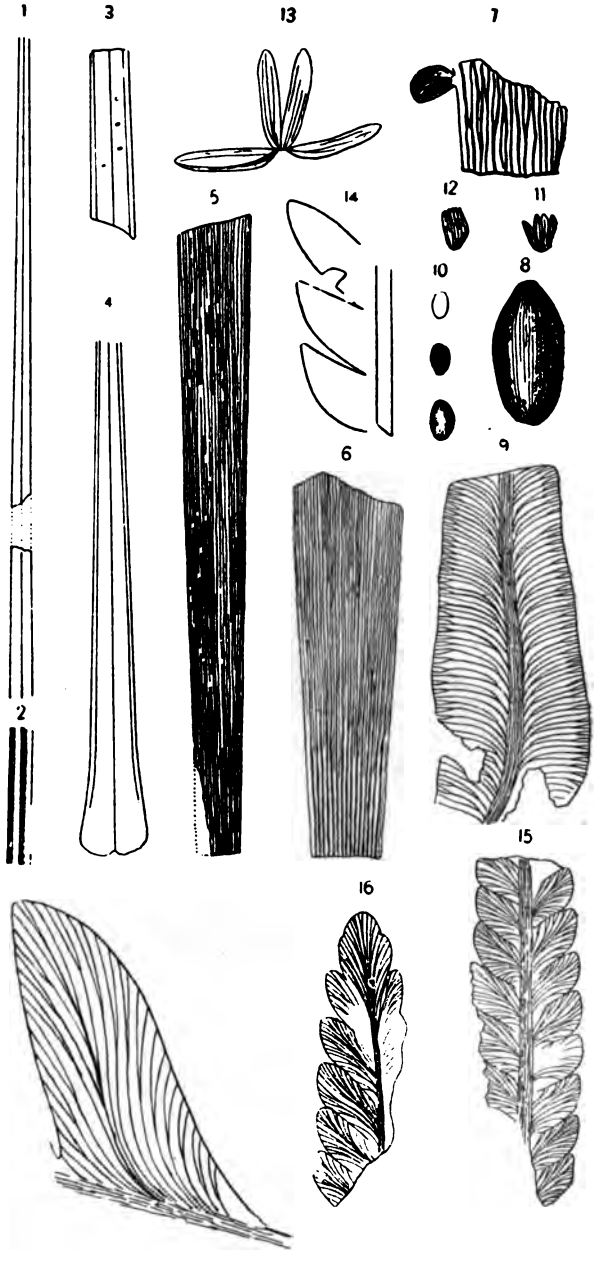


KANSAS PERMIAN PLANTS.



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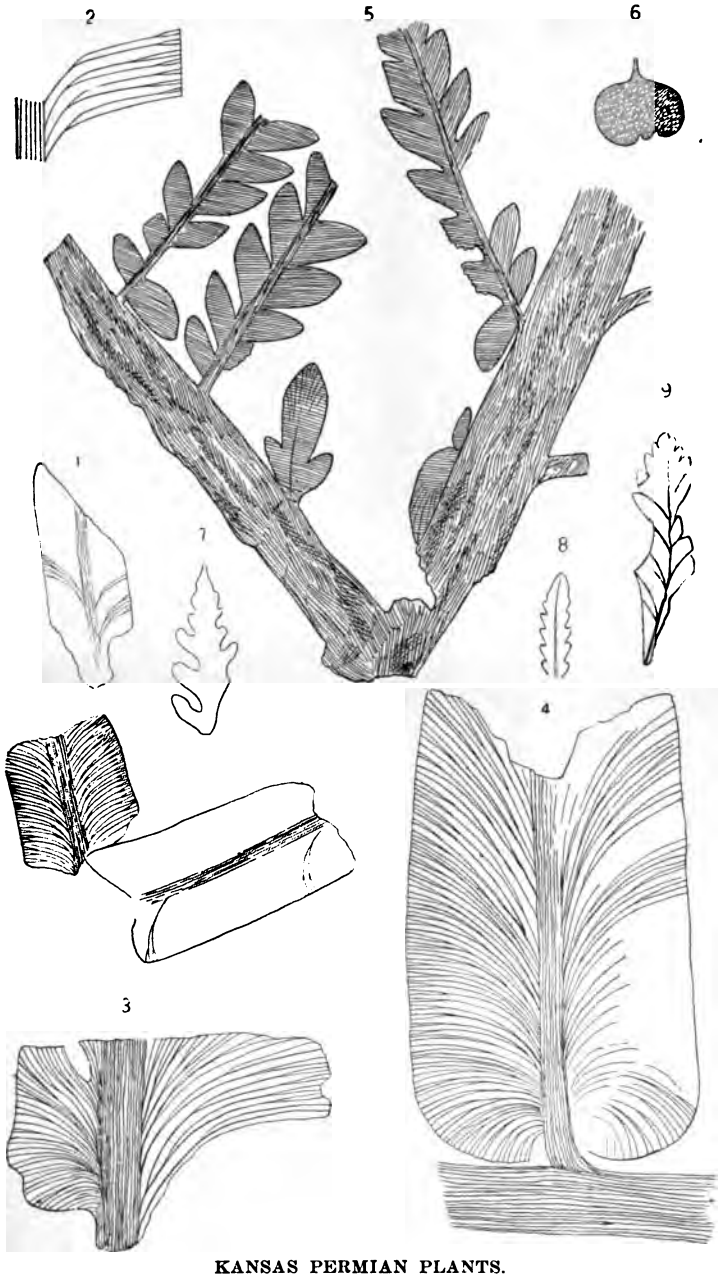

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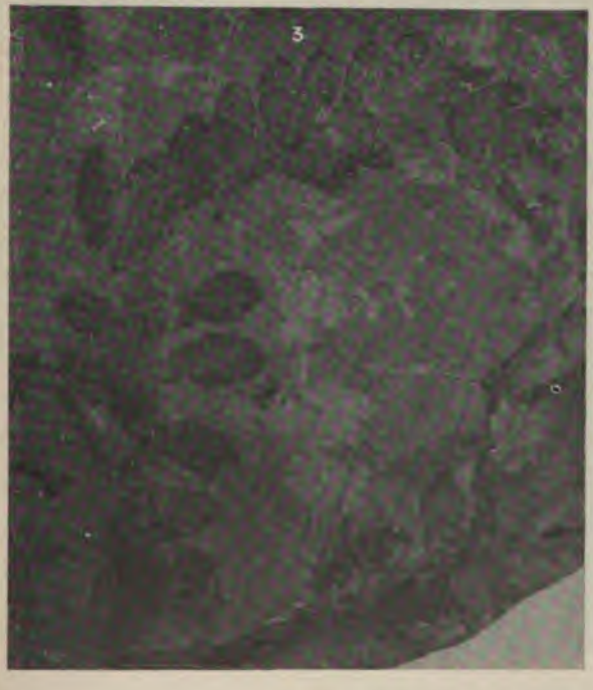

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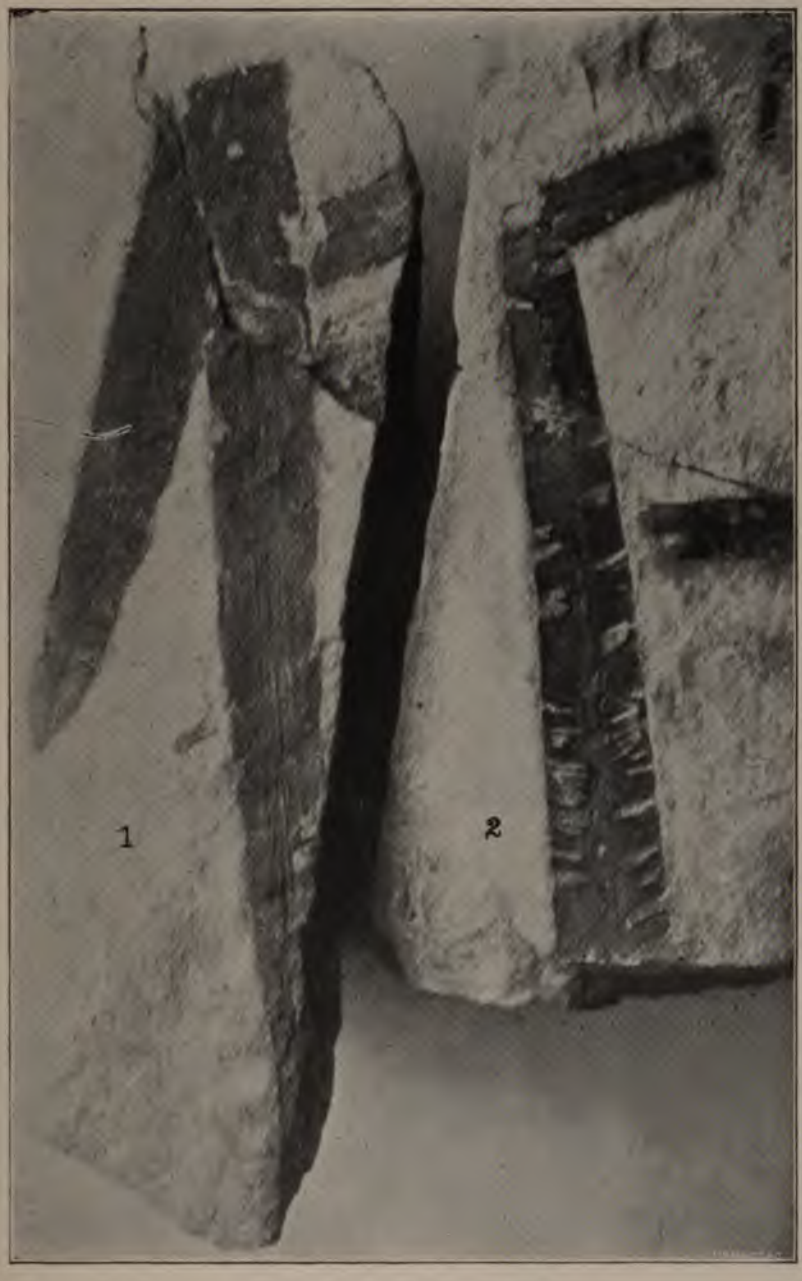

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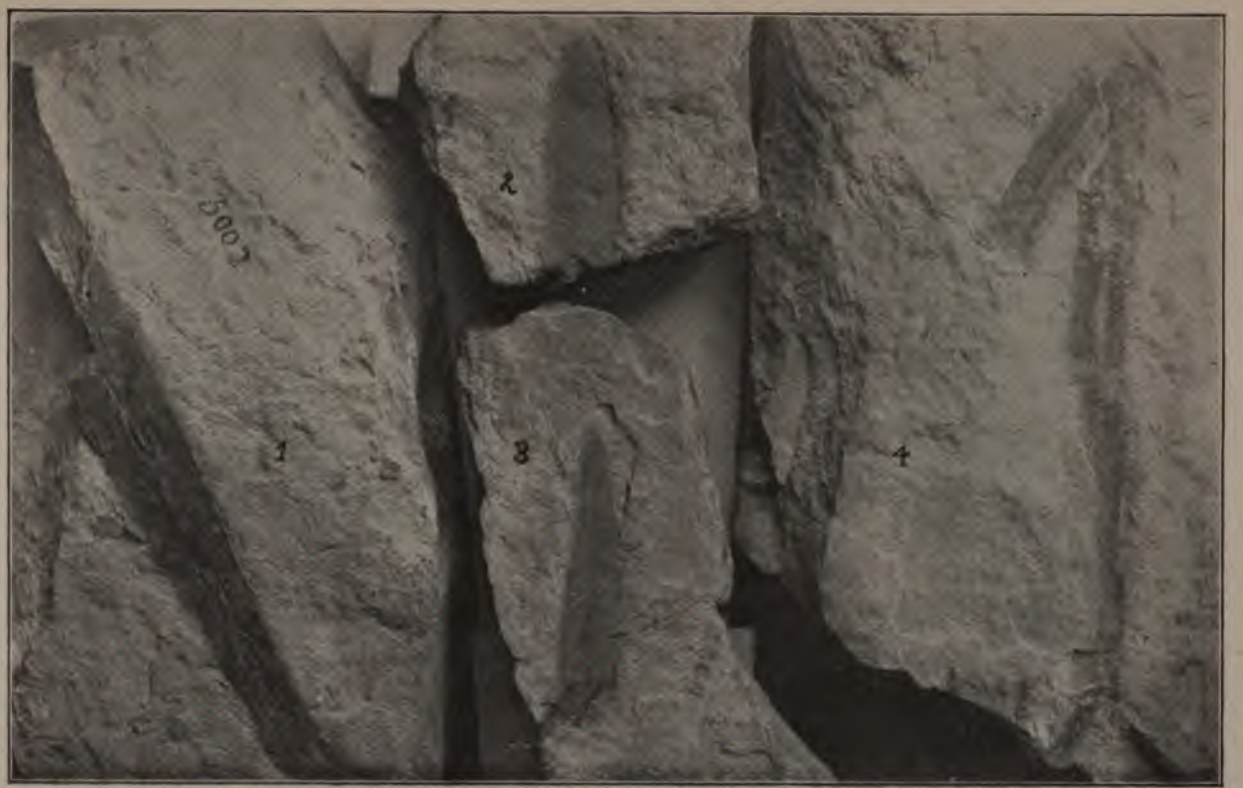


KANSAS PERMIAN PLANTS.

KANSAS PERMIAN PLANTS.

CHAPTER XI.

COCKROACHES OF THE KANSAS COAL MEASURES AND OF THE KANSAS PERMIAN.

BY E. H. SELLARDS.

Introduction.

AMONG a small lot of fossil plants obtained in 1878 or 1879 from the old fair-grounds one mile east of Lawrence, Kan., by the early geologist and collector, Mr. Joseph Savage, was found a single cockroach wing. This specimen, sent on with the plants to Lesquereux, and subsequently described by Scudder (Mem. Bost. Soc. Nat. History, vol. 4, No. 9, p. 410, pl. 32, fig. 4, 1890) as *Etoblattina occidentalis*, remained for more than twenty-one years the only fossil insect known from the Kansas Paleozoic. During the spring of 1901 insects were rediscovered in the Le Roy shales on the Haverkampf farm, three miles southeast of Lawrence. They were found here among a small lot of fossil plants collected from this locality by Mr. H. T. Martin and the writer. It was found later that the Le Roy shales held insects in various localities about Lawrence. A single cockroach wing and fragments of a second wing had been previously found by the writer among Permian plants collected in 1900 from the Wellington shales of Dickinson county, Kansas. No opportunity to revisit the Permian locality presented itself until the summer of 1902, at which time the writer discovered a horizon in the Wellington shales exceptionally rich in insects. From these localities has been brought together the material forming the basis of the present paper.

The Coal Measures collections are the following: One lot of 228 specimens (170 cockroaches) obtained by the Kansas University Geological Survey during the summer of 1901.[304] This collection is deposited in the museum of the University of Kansas. A second lot of 61 specimens (42 cockroaches) was

304. The members of the Geological Survey party making this collection were H. T. Martin, Sydney Prentice, and the writer, and, in addition, during a part of the time, Dr. S. W. Williston, Walter Meek, E. E. Brown, and D. F. McFarland.

obtained by the writer from the Le Roy shales during the summer of 1902, and lastly, a third lot of 109 specimens (91 cockroaches) collected by the writer for the Yale Museum during the summer of 1903, and contained in the Yale Museum. All of the Permian cockroaches, with the exception of two specimens belonging to the University of Kansas, are from the writer's collection of Permian insects made during the summers of 1902 and 1903. All specimens described are referred by number to their respective collection.

Three publications[305] on the structure of Paleozoic cockroaches, based in part on these collections, in part on collections from other localities, have been given out. In these publications are described such of the new forms as are necessary to illustrate the structural characters discussed. Many additional species are described in this paper.

The Le Roy shales, from which the Coal Measures material comes, are placed in the Upper Coal Measures. The insects in this formation are found along with the plants in light-colored clays and shales grading into fine-grained sandstones. Occasionally also insects are found in the dark-colored carbonaceous shales. The Wellington shales in which are found the later insects, are referred, on the evidence of both plants and insects, to the Permian, a correlation which receives unqualified support from both the plant and insect fossils. The horizon in the Wellington holding the insect remains is a fine-grained limestone containing more or less silicious material. The rock occurs in thin-bedded, light-colored layers. Most of the insects have been obtained from a single locality three and one-half miles southeast of Banner City, in Dickinson county. This locality when first discovered was believed to lie in the Marion formation, and was so placed in the writer's first announcement of the discovery of the insects (Amer. Jour. Sci., vol. 16, p. 323, 1903). The present reference of the locality to the overlying Wellington is in accordance with the correlations of the Permian by J. W. Beede given in this volume. In addition to the Banner City locality a few insects have been obtained from a similar outcrop near Peabody, thirty miles south. It is not to be doubted that other localities rich in in-

305. Some New Structural Characters of Paleozoic Cockroaches (Amer. Jour. Sci., 4th ser., vol. XV, April, 1903, pp. 307-315). A Study of the Structure of Paleozoic Cockroaches, with Description of New Forms from the Coal Measures (*ibid*, vol. XVIII, August-September, 1904, pp. 113-134, and 213-227). Geological History of Cockroaches (Popular Science Monthly, March, 1906, pp. 244-250).

sects will be found ultimately in both Permian and Coal Measures deposits of Kansas.

The Kansas collections are rich in immature, or nymph, cockroaches. Bodies of adult cockroaches are seldom preserved, not a single specimen occurring among the Kansas collections, although not less than 107 nymphs or parts of nymphs are present. These are in most, perhaps in all, cases the molts or cast off integuments of nymphs. The molts are lighter, float more readily, escape the danger of being eaten by insect-feeding animals, resist decay, and are in every way better adapted for preservation than are the soft bodies of adults.

The body structure of the *Paleoblattidæ* is, so far as known, essentially the same as that of modern cockroaches. The body has the same flattened form; the small head usually hidden by the rounded pronotum; antennæ seldom complete, but evidently long and slender; eyes, so far as can be seen in the fossil condition, like those of modern forms; the mouth-parts apparently have failed of preservation; of the legs the coxa and trochanter are occasionally seen, the femur and tibia more often; the more delicate tarsus, however, is indistinctly preserved; the tibia, in some species at least, is spinous; in other species evidence of spines is lacking; the abdomen is broadest at the middle; the ten terga in the nymph stages of both male and female are distinct; the first tergum is small, about as board as long; the following increase in length up to the fourth or fifth, where the abdomen is broadest, beyond which the abdomen narrows to the rounded tenth tergum; the cerci project from beneath and at the side of the tenth tergum; the sterna, partly covered by the terga, are less definitely known; occasionally sterna three to nine are seen, evidently little modified, lying beneath their respective terga. These individuals are without doubt males. Others (females, as shown by the presence of the ovipositor) have a much enlarged seventh sternum lying beneath the seventh, eighth and a part of the ninth terga. A striking feature seen on some Paleozoic nymphs is the presence of a straight or sword-shaped ovipositor projecting from the abdomen, in some genera as long as the abdomen itself. As seen in the later nymph stages the parts of the ovipositor are closely united, the whole appearing as a straight resistant organ projecting from beneath the terga and from above the sterna. A young nymph of *Etoblattina*

obtained by the writer from the Le Roy shales during the summer of 1902, and lastly, a third lot of 109 specimens (91 cockroaches) collected by the writer for the Yale Museum during the summer of 1903, and contained in the Yale Museum. All of the Permian cockroaches, with the exception of two specimens belonging to the University of Kansas, are from the writer's collection of Permian insects made during the summers of 1902 and 1903. All specimens described are referred by number to their respective collection.

Three publications[305] on the structure of Paleozoic cockroaches, based in part on these collections, in part on collections from other localities, have been given out. In these publications are described such of the new forms as are necessary to illustrate the structural characters discussed. Many additional species are described in this paper.

The Le Roy shales, from which the Coal Measures material comes, are placed in the Upper Coal Measures. The insects in this formation are found along with the plants in light-colored clays and shales grading into fine-grained sandstones. Occasionally also insects are found in the dark-colored carbonaceous shales. The Wellington shales in which are found the later insects, are referred, on the evidence of both plants and insects, to the Permian, a correlation which receives unqualified support from both the plant and insect fossils. The horizon in the Wellington holding the insect remains is a fine-grained limestone containing more or less silicious material. The rock occurs in thin-bedded, light-colored layers. Most of the insects have been obtained from a single locality three and one-half miles southeast of Banner City, in Dickinson county. This locality when first discovered was believed to lie in the Marion formation, and was so placed in the writer's first announcement of the discovery of the insects (Amer. Jour. Sci., vol. 16, p. 323, 1903). The present reference of the locality to the overlying Wellington is in accordance with the correlations of the Permian by J. W. Beede given in this volume. In addition to the Banner City locality a few insects have been obtained from a similar outcrop near Peabody, thirty miles south. It is not to be doubted that other localities rich in in-

305. Some New Structural Characters of Paleozoic Cockroaches (Amer. Jour. Sci., 4th ser., vol. XV, April, 1903, pp. 307-315). A Study of the Structure of Paleozoic Cockroaches, with Description of New Forms from the Coal Measures (*ibid*, vol. XVIII, August-September, 1904, pp. 113-134, and 213-227). Geological History of Cockroaches (Popular Science Monthly, March, 1906, pp. 244-250).

mazona from Mazon Creek, Ill., by a fortunate fracture of the matrix, reveals the parts of the ovipositor before they have become united. An illustration of this specimen has been given in the writer's paper on the "Structure of Paleozoic Cockroaches," referred to above. The ovipositor is here seen to consist of four approximately equal parts, or two pairs. A third smaller pair is probably present, although its preservation is obscure.

The naming of the wing veins is that coming into general use in entomological writings. Aside from the veins of the anal area five main veins of the wing are recognized. The costa of the front wing is doubtless marginal. A sharp fold is seen running across the humeral shoulder of the wing, and it is possible that the costa lies at the bottom of this fold. The subcosta is uniformly a moderately developed vein with from few to many superior branches, arising either in a cluster at or near the base (*Mylacrinariæ*) or as successive branches from the main vein (*Blattinariæ*). The radial vein often comes close to the subcosta but with few exceptions remains free to the base. Its branches are superior, the earlier ones usually being compound.

The hind wing of the cockroach, even as early as Coal Measure times, was essentially different from the front. A thinner and broader expanse of the wing is supported by a deep subcostal fold, a partial basal union of some of the main veins, and an imperfectly radiated arrangement of the veins toward the inner expanded side of the wing. The costa is submarginal and extends often one-half the length of the wing. It is usually simple, but occasionally gives off one or two superior branches. The subcostal fold is particularly well marked near the base of the wing, fading out toward the tip. The subcosta lies at the bottom of the subcostal fold and gives off branches beyond the termination of the costa. The radius is almost invariably united for some distance with the subcosta and in such a way as to give it the appearance of a radial sector. That it is not the radial sector is, however, made evident by the fact that in rare instances it continues free to the base. According to Comstock and Needham[306] the reduction or absence of the radial sector is a feature common not only to the hind wings of modern cockroaches, but also to the hind wings of all modern Orthoptera. The media of the more advanced

306. American Naturalist, vol. XXXIII, p. 575, 1899.

types is united at the base with the radius and subcosta. The cubitus, on the contrary, is free from all other veins and at the base turns down toward the inner border, as do the trachea in the wings of nymphs. That this is the normal course of the cubitus is evident from its occurrence in several species. Following the cubitus the first anal vein is usually simple, but occasionally gives off one or two inferior branches. Its trachea is strong to the base and, like that of the cubitus, turns toward the ventral side of the wing. The second anal vein normally gives off a few inferior branches resembling those of the cubitus. The trachea of this vein also is free to the base.

Formerly the writer was of the view that the fold in the hind wing of cockroaches, while present among the Permian species, had not developed as early as Coal Measure time. European writers have, however, illustrated specimens which leave apparently no doubt that the fold in the wing was present as early as Coal Measure time.

Order ORTHOPTERA.

Superfamily BLATTACEA Sellards.

Family PALEOBLATTIDÆ (*Paleoblattariæ* Scudder).

Mylacris SCUDDER.

Geol. Survey of Illinois, vol. 3, p. 568, 1868.

One species only of the genus *Mylacris* has been found in the Kansas deposits. The genus as employed by Scudder is distinguished from other genera of the *Mylacrinariæ* by the comparatively large area occupied by the subcostal and radial areas, the subcostal especially being large, defined as larger than the radial. In general, broad-winged species with subcostal area large as compared with the radial are referred to this genus. *Mylacris* has not been found in the Permian, the species here described from the Upper Coal Measures being the latest of the genus known.

Mylacris latissima sp. nov. Pl. LXXI, fig. 5; pl. LXXXII, fig. 2.

Tegmina very broad in proportion to the length; widest at the middle of the anal area. Costal and inner borders both slightly arched, sloping gradually to an obtuse apex placed in about the center line of the wing. Subcostal area broad, extending to about the middle line of the wing; two main branches are distinguishable. The radial area extends to near

the apex; four oblique branches pass to the costal border, the first and second of which are compound. The median area is strongly developed and fills the apical part of the wing; its first branch, given off near the base, is long, twice forked, and runs through the center of the wing to the apex; numerous other superior branches go to the apex; the main vein gives off a thin, simple, inferior branch about the middle of its course. The cubitus has a sinuous course and reaches two-thirds the length of the tegmina. The main vein and its branches are very thin and delicate, flexuous, and inconstant in their course. The first branch presents an anomalous condition; it forks at a wide angle and one division runs directly across the second branch of the cubitus and unites with the first inferior division of the third branch throughout the distal half of its length. The basal half of both of these veins—the second branch of the cubitus, and the first division of the third branch—is thin and indistinct and is apparently becoming aborted. The third cubital branch gives off four inferior veins. The anal area extends approximately one-third the length of the inner border. It is broad, triangular, marked off by a deep furrow, and has about nine thin, mostly simple veins.

The broad wing and the habit of branching of the cubitus suggest a comparison with *M. bretonensis* Scudder from Cape Breton. *M. latissima*, however, is much larger, with the main veins free at the base, the radial area less developed, the median much more so, and the first branch originating earlier. Although peculiar in the arrangement of the cubital branches, this species presents nothing of the anomalous disposition of the anal veins described for *M. bretonensis*.

Formation and locality: Le Roy shales Upper Coal Measures, Lawrence, Kan. Type No. 36, University of Kansas collection.

Promylacris.

Scudder, Proc. Acad. Nat. Sci. Phila., p. 34, 1885.

To this genus is referred those species having small subcostal and very large radial areas. Most of the species of the genus are small.

Promylacris radialis sp. nov. Pl. LXX, fig. 8; pl. LXXXI, fig. 5.

Tegmina slender, costal border but slightly arched; apex obtuse. The subcostal area is small, the main vein having only three main branches, and these originating close together

near the base. The radial, on the contrary, is very strongly developed, occupying almost half of the tegmina. The main trunk of the radius curves toward the inner border, turning up only at the apex. It gives off throughout its course numerous superior branches, most of which are once forked. These go to the costal border and the apex. The median remains simple until beyond the middle of the wing, and is apparently but slightly developed. The cubitus has simple, oblique, straight branches.

This species is much like *P. harei* Scudder, from a lower horizon at Kansas City, Mo. A comparison with the type specimen of the latter species, however, convinces me that a specific difference exists between the specimens. *P. radialis* is larger, and the costal border less arched. The radial area has a much greater development, while the costal area is smaller.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Type No. 88, University of Kansas collection.

Etoblattina.

Scudder, Mem. Bost. Soc. Nat. Hist., pp. 56-59, 1879.

Etoblattina scudderi sp. nov. Pl. LXXI, figs. 3, 6; pl. LXXVIII, figs. 1, 2, 4.

Large cockroaches, front and hind wings of approximately equal size. Costal border of tegmina gently arched. Subcostal area strongly developed, reaching beyond the middle of the wing; branches oblique, mostly simple. Radial area reaching to near the apex, branching early, opposite or in front of the middle of the anal area. The media is less developed than the radius and branches later. The cubital area is long and narrow, its branches oblique, nearly straight, and parallel. The anal area is striking because of its extreme length. It reaches back beyond the basal third of the wing, is narrow and pointed. The five or six veins are mostly simple and parallel and nearly straight, running in a direction almost parallel with the long axis of the wing. All the veins of the tegmina are strong and large and stand out prominently from the wing. The impression made by the wing is of a yellowish brown color.

The hind wing is thinner than the front. It is shorter, but with its expanded anal area nearly as broad, giving it a more oval outline. The costa extends as a thin vein approximately

one-third the length of the wing before meeting the costal border and gives off two or three thin, oblique, superior branches, which either reach the border or are lost in the fine reticulated meshes of the wing near the border. The subcosta extends as a narrow area almost to the tip of the wing. A few oblique forked branches are given off back of the termination of the costa. The radial area of the hind wing is more narrow than that of the front. The radius branches first about the middle of the wing, and has only a few divisions and these go to the apex. The media is more strongly developed and gives off several superior branches which go to the inner border. The cubital area is strong and has numerous parallel nearly straight veins and also one or two offshoots from the upper side. The vein occupying the anal furrow is once or twice forked. The first anal vein gives off three branches from the lower side, the first two of which end on the second anal vein. A few other longitudinal anal veins are present. The membrane of both front and hind wings is finely reticulated.

The description of the front wing is based on nine well-preserved tegmina, all of which agree closely in their specific characters. Radial branches one and two, both once or twice forked, usually arise very close together. Wing No. 1 of the writer's collection has, however, these two branches united for some distance from their origin. There remains also the vestige of an earlier radial branch which, arising nearer the base of the radius, soon fades out and is lost in the membrane. No. 4 of the Yale collection and No. 44 of the Kansas collection have also the first two radial branches united at the base, but lack the vestige of the earlier branch. No. 23 of the Yale collection shows the two tegmina in position partly overlapping each other and somewhat arched.

The hind wings are of particular interest, as there are seven exceptionally well-preserved specimens. The connection between the front and hind wings is inferred from association, this being the only species of large cockroaches found at the locality. This inference is supported by certain resemblances in the venation in the central part of the wing. The vein interpreted as the costa is thin and wavering but reaches half the length of the wing and gives off one or two branches. The subcosta reaches well toward the tip of the wing and has a few branches beyond the termination of the costa. The radius

unites with the subcosta, 4 or 5 mm. from the base, thus giving it much the appearance of a strong radial sector. The partial basal union of the main veins and the deep subcostal fold are apparently modifications for securing support for the broad but thin hind wing. The forking of the vein occupying the anal furrow is seen on six well-preserved specimens and is evidently the normal character. In five of the six it is simply forked, but in one case, wing No. 2, University of Kansas collection, a second branch is seen near the tip. The manner in which branches are given off from the first anal vein beyond the anal furrow and their termination on the following anal vein is very suggestive of some Permian hind wings in which a fold is developed along this line. Occasionally among the Coal Measure wings the part of the anal area beyond this line is seen folded under, as in wing No. 203, University of Kansas collection.

The costa, subcosta and anal veins of the hind wing are thus seen to differ entirely from the same veins in the front wing. Some resemblances remain, however, in the veins of the central part of the wing. The radius of the hind wing, except for its basal union with the subcosta, is not unlike that of the front wing. The media also, although occupying more area relatively, is otherwise not unlike the media of the front wing. The cubitus of both wings gives off one or two thin branches from the upper side.

It seems probable that the heavy-bodied nymph shown in figure 3, plate LXXII, may be the immature form of *E. scudderi*, as it is apparently too large for the young of any of the associated species.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. University of Kansas collection, Nos. 9, 44, 96, 100, 109, 141, 157, 202, 140?; Yale collection, Nos. 4, 23, 98, and one specimen in lot No. 2685; author's collections, Nos. 1, 3, 37. Hind wing, University of Kansas, Nos. 2, 15, 36, 203, 210; Yale, No. 81; author's collections, Nos. 2, 4, 27?.

Etoblattina obscura sp. nov. Pl. LXX, fig. 5; pl. LXXIX, figs. 1, 2; pl. LXXXI, figs. 2, 4; pl. LXXXIII, figs. 1, 2.

Cockroaches with arched, thick, dark-colored front wings, in which the venation is indistinct or partly obscured; inner border nearly straight, slightly interrupted by the anal area. Subcosta variable in extent, reaching from less than one-third

to one-half the length of the costal border and giving off a variable number of very oblique, mostly simple, branches. Radius also variable in extent, falling somewhat or considerably short of the apex. The first radial branch is given off from 3½ to 7 mm. from the base. The media branches before reaching the middle of the wing, its several oblique divisions filling the apex. The cubital area extends two-thirds to three-fourths the length of the inner border, its six to eight branches simple or once forked. The anal area is strongly marked and the veins numerous. The species resembles *E. communis*, a very abundant species in the Permo-Carboniferous of Cassville, W. Va., but there is a constant difference in the extent of the subcosta, which, although variable in the Kansas species, is always shorter.

This is one of the very common species of the Lawrence shales. Fourteen specimens are referred to it. The tegmina are variable in the relative extent of the main veins and their branches as well as in the number of branches. They are constant, however, in the thick and dark membrane, and in the arched form with rounded apex. The variation in size is slight. Specimen No. 119, University of Kansas collection, may be taken as typical, the shape and venation of the wing being that characteristic of the species. No. 156 of the same collection has the two tegmina preserved. The radial areas of the two front wings differ slightly in their method of forking. The pronotum, as seen in specimen No. 129 of the University of Kansas collection, is of the normal rounded *Etoblattina* type.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. University of Kansas collection, Nos. 43, 68, 87, 119, 149, 156, 172, 191, 199, and 204; No. 75 of the Yale collection; and Nos. 13 and 59 of the author's collection.

Etoblattina savagi sp. n. Pl. LXXI, fig. 4; pl. LXXXII, fig. 1.

Medium-sized cockroaches with broad front wings. Costal border of tegmina regularly and strongly curved, inner border straight as far as the apical margin, apex placed on about the middle line of the wing, obtusely pointed. Subcostal area short, not reaching to the middle. Radial area broad and occupying over two-fifths of the width of the wing. The first branch is given off opposite the end of the anal area, is soon forked, both branches again widely forked, all the divisions running to the costal border at a steep angle. The second

branch is more oblique and gives off three superior branches. Three other oblique, simple, or forked branches pass to the border. The media is much developed, its branches filling the apex of the wing. The first five cubital branches are parallel, simple, and nearly straight. The anal area is well marked, broad, but short, and has in the type seven simple veins. Length of tegmina, about 26 mm., width 11 mm.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Type No. 57, University of Kansas collection. The species is named for Mr. Joseph Savage.

Etoblattina brevi-cubitalis sp. nov. Pl. LXXX, fig. 2.

Tegmina approximately two and one-half times as long as wide. Costal border arched, inner border nearly straight. Widest part about the end of the anal area, gradually reduced to an obtusely pointed apex. Subcostal area of slight extent, reaching hardly to the middle, giving off about six oblique, simple or forked branches. The radial area reaches nearly to the apex; its first branch is given off before the middle of the anal area. Four or five other simple or forked branches arise at equal distances from the main stem. The median branches fill the apex of the wing. The first branch arises opposite the end of the anal area. The cubitus beyond the basal curve runs in a nearly straight course, striking the border at the distal end of the middle third. It has crowded, mostly simple, very oblique, parallel branches. The anal area is likewise crowded with numerous, mostly simple, cross-veins.

The thirteen individuals referred to this species agree closely in size, being from 22 to 25 mm. long, and from 9 to 11 mm. wide. The distinctive features of the species are the direct course of the comparatively short cubitus with its very oblique branches, and the numerous anal veins. The shape of the wing is quite constant, being always slightly arched. The subcostal area varies in extent from 9 to 14 mm. from the base. The radius uniformly reaches nearly to the apex. The anal veins are always numerous and close, twelve to fourteen in number. The species differs from *E. occidentalis* in the greater number of anal veins and the shorter cubitus with more oblique branches.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. University of Kansas collection, Nos. 63, 39, 10, 65, 69, 90, 97, 113, 131; Yale collection, Nos. 10, 56, 67?; author's collection, Nos. 18, 19, 20.

Etoblattina occidentalis. Pl. LXX, figs. 1, 2; pl. LXXVIII, fig. 3; pl. LXXIX, fig. 4.

Scudder, Mem. Boston Soc. Nat. Hist., vol. 4, p. 410, pl. 32, fig. 4, 1890.

This species, originally described from a near-by locality in the Lawrence shales, is found to be represented in the present collections. The type specimen seems to have been somewhat larger than is the average for the species.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan.

Etoblattina ? coriacea Sellards. Pl. LXXVI, fig. 29; pl. LXXVII, fig. 9.

Sellards, Amer. Jour. Sci., vol. XVIII, p. 213, 1904, fig. 29.

A new species of cockroaches in the Le Roy shales is represented by one specimen and its counterpart. The slender tegmina is unusually coriaceous, the veins, except those of the anal area, being entirely obscured. The most marked characters are the extreme slenderness of the tegmina, its thick texture, the rounded prominent shoulder at the base, and the squarrose appearance of the anal area. The form is evidently specifically if not generically distinct from any heretofore described. Length of tegmina, 20 mm.; width 7 mm.

Formation and locality: Upper Coal Measures, Lawrence, Kan. Type No. 115, University of Kansas collection.

Etoblattina fulva sp. nov. Pl. LXX, figs. 4, 6, 9; pl. LXXIX, fig. 3; pl. LXXXI, figs. 3, 6.

Medium-sized cockroaches with tegmina preserving as brownish colored impressions. Subcostal area reaching hardly beyond the middle of the wing. The main vein curved and giving off arched simple branches. The radius falls a little short of the apex. The media branches before reaching the middle of the wing. Its branches are strong and longitudinal, forking at the tips. The cubitus reaches beyond the inner angle of the lower border. The anal furrow is well marked. The area is provided with eight to ten simple veins.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Nos. 130, 142, 192 and 28, University of Kansas collection; Nos. 37 and 80, Yale collection.

Etoblattina permiana sp. nov.

Subcostal area broad, but short, hardly reaching beyond the middle of the wing; branches numerous, mostly simple, arched in passing from the main vein to the border. Radius and branches prominent. First and second superior branches

strong, both twice forked. A third simple branch is given off beyond the middle of the wing. The radius terminates a little short of the apex. Median area also well developed. The main vein at the base lies close to the radius but apparently does not unite with it. First branch of the media strong, two or three times forked. The veins of the cubital area, like those of the subcostal, are lighter and less deeply impressed than those of the central part of the wing. The cubitus reaches almost to the inner angle of the wing. The main vein gives off slender, gracefully curved branches, the first four or five of which are simple. Anal area rather long in proportion to its width; apparently easily detached. Anal veins twelve to fourteen, the first four of which occupy more than one-half of the area. Length of wing estimated at 19 to 20 mm.; width, 6½ to 7 mm.

The cockroaches of this species are the largest yet found in the Kansas Permian. It seems not to have been a common species, only four specimens having come to light. The wing membrane as seen in exceptionally well-preserved specimens is finely reticulated. Three of the specimens are preserved in flinty and very hard limestone, the fourth in the ordinary limestone.

Formation and locality: Wellington shales, Dickinson county, Kansas. Types in the University of Kansas collection, and No. 1001 of the author's collection.

Etoblattina curta sp. nov. Pl. LXXIII, figs. 1, 4.

Wings of medium size, broad in proportion to their length; apex rounded. Veins at the base of the wing clearly distinct; subcosta reaching to or beyond the middle of the wing; branches oblique; radius reaching hardly to the apex; four or five superior branches, the second forked, others usually simple; median area large, branches parallel, simple to near their tip; cubitus long, strong at the base, fading out towards the tip; first four basal branches simple, strong, and deeply impressed in the wing membrane, the following four or five branches indistinct. Length estimated at 13 to 15 mm.; width, 4½ to 5 mm.

Ten specimens are referred to this species. The wide separation of the main veins at the base distinguishes the species from most of the other Permian forms. The radius of No. 8 has five superior branches; that of No. 111 has only four; the

basal part of the fifth, however, remains, indicating that it is disappearing by reduction. The basal part of the cubitus and its earlier branches are very strong, while the distal part of the same area is very weak. The anal area seems to have been easily detached and is seldom preserved in place. It was of medium extent. About twelve anal veins are present, the first three of which occupy one-half of the area, while the last six or seven are crowded toward the inner border.

Formation and locality: Wellington shales, Banner City; author's collection, Nos. 8, 44, 47, 111, 162, 215, 248, 257, 354, and 1007.

Etoblattina pecta sp. nov. Pl. LXXIII, fig. 2.

Costal border regularly arched. Subcostal area broad, main vein extending perhaps one-half the length of the wing, with numerous oblique superior branches. Radial area large, probably reaching to the apex of the wing; first branch, given off some distance from the base, has three superior branches; the second branch is once forked; two other simple branches are given off. The media is probably free to the base, but lies very close to the radius. It remains simple beyond the basal third of the wing. Cubitus not strong, probably of medium extent. Anal furrow not distinct.

One specimen only of this species is recognized. The wing membrane is thin, and the framework of veins rather light. The species can be readily distinguished from *E. curta* by the close approximation of the radius and media at the base, as well as by the branched first division of the radius, and the large extent of the radial area. Length estimated at 12 mm.

A second specimen, No. 131, is referred with some doubt to this species. It is very similar in the close approximation of the main veins at the base. It is perhaps a little smaller, measuring 10 or 11 mm. long, 4 mm. wide. The first branch of the radius of this specimen is once branched only.

Formation and locality: Wellington shales, Banner City. Type, No. 1013, author's collection.

Archimylacris.

Scudder, Dawson's Acad. Geol., vol. 2, p. 388, 1868.

Archimylacris recta sp. nov.

Tegmina very straight, more than twice as long as broad, costal and ventral borders nearly straight, apex obtuse. Subcostal area extending to near the middle of the wing; main

vein straight, branches very oblique, simple, and straight. Radial strongly developed, curved up a little at the base, then passing with a slightly flexuous course through the middle of the wing. The first branch arises close to the base. Numerous other simple or compound branches, about nine in all, pass obliquely to the costal border. The media branches first opposite the end of the anal area, its first division in the type specimen ending blindly before reaching the border. Three other branches are given off, two of which are forked. The cubital area extends about two-thirds the length of the wing. Six branches are given off, three of which are forked. The first branch presents an anomalous condition occasionally seen in the cubital area of other species, one division running directly across the second cubital branch. The anal furrow is distinct. The anal area has four simple curved veins.

The large area occupied by the radius brings this species within the genus *Archimylacris*. The only species with which it admits of close comparison is *A. parallela* Scudder, from a much lower horizon. The radius of this new species branches much earlier and the subcosta is shorter. Length of tegmina, 24 mm.; width, 10 mm.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Type No. 138, University of Kansas collection.

Gerablattina.

Scudder, Mem. Bost. Soc. Nat. Hist., vol. III, p. 97, 1879.

Gerablattina arcuata. Pl. LXX, fig. 3; pl. LXXXII, fig. 4; pl. LXXVII, fig. 10.

Sellards, Amer. Jour. Sci., vol. 18, p. 216, text fig. 1; pl. I, fig. 7.

Tegmina about twice as long as broad, outer border strongly arched, the apex rounded; inner border nearly straight, interrupted by the anal area. Subcosta arched parallel to the costal border, reaching three-fourths the length of the wing; branches numerous, simple, thin, curved and parallel. The radius is but slightly developed, branches first beyond the middle of the wing and falls short of the apex. The media, like the radius, occupies a comparatively small area, and remains simple until beyond the middle of the wing, its four simple oblique branches filling the apex. The cubitus is strongly developed and reaches almost to the apex. The first five branches are simple and nearly straight; the others are more oblique, closer and curved. The anal area is well marked and has about seven simple veins. In texture and general ap-

reaching to near the apex and giving off five or six simple or forked branches, the first of which originates beyond the basal third of the wing. The media and its branches fill the apex. The branches are simple, long, parallel. The cubitus is long, reaching along the inner border almost to the apex. Its numerous branches are mostly simple. The anal area is well marked off, concave, and has six to nine simple veins. Length of tegmina, 9 to 11 mm.; width, 3 to 3½ mm.

Six specimens of this species have been found. The species is easily recognized by the small, compact tegmina with numerous veins. There is considerable variation among the several specimens referred to the species, and possibly more than one species is represented. Nos. 850 and 1011 are smaller and have shorter subcosta and more numerous veins.

Formation and locality: Wellington shales, Banner City; Nos. 123, 476, 850, 1011, 770, 463, 656, 1008, author's collection.

Puknoblattina curvata sp. n. Pl. LXXIII, fig. 3.

Wings strongly arched. The subcosta reaches to the middle of the wing and is supplied with several branches. The radius reaches nearly to the apex and has numerous superior branches. The media curves downward strongly and has strong parallel branches. The cubitus is curved and has strong parallel branches.

Formation and locality: Wellington shales, Banner City.

NYMPHS OF COCKROACHES.

The most abundant type of nymph cockroaches at the Lawrence locality is the form previously described (Amer. Jour. Sci., vol. 18, p. 131, text figs. 17 to 21, 1904) under the term *Etoblattina juvenis*. The abdomen of this type is large and broad, the terga have well-developed free edges, and the sterna have rounded corners. Two instructive individuals of the species lying on a small slab are shown in their relative positions in figure 7, plate LXXVI. The dorsal integument of the nymph at the right of the figure is broken down the center, thus exposing the basal elements of the legs. The basal part of the ovipositor, 9 mm. long, is preserved in place on this specimen. Parts of the body are scattered about on the slab. Detached terga, with their pointed edges, and one of the sterna, with rounded edges, are seen lying between the two nymphs. The nymph on the left of the figure is more nearly

entire. The head is displaced to the right of the pronotum. The antennæ are very well preserved. On the pronotum is seen a circular mark which seems to be characteristic of the species. Traces of the venation are evident, the cubitus and its branches, as is usual among nymphs, being the first to appear. Parts of the legs are exposed at the sides of the body. The tibia is spinous and the tarsus apparently long. The pointed free edges of the terga are evident. The cerci, although incomplete, are unusually long. A considerable number of specimens of this general type and in various stages of development have been obtained from the Le Roy shales. During the early stages the corners of the pronotum are rounded. As the nymph approaches maturity the corners become more pointed and the pronotum broader in proportion to its width. The cubitus is the first of the veins to appear in the developing wing, and in some of the larger specimens most of the veins of this area can be seen.

The first three or four terga and sterna of the specimen illustrated by figure 18, plate LXXV, are seen in place, the sterna showing as impressions through the terga. In the wings of this specimen traces of the venation are evident, as is also the thickened spot at the base, which marks the point at which the articulation of the wing with the body is found. The detached wing of figure 20 of the same plate is from a more mature individual, and traces of all of the main veins are to be seen. The cubitus especially is well developed. Two or three anal veins are to be seen also, although the anal area is not as yet distinctly marked off. The detached wing photographed, figure 3, plate LXXXII, has reached about the same stage of development and shows a similar distribution of veins. The trochanter, femur and tibia of one leg, with a detached tergum at the side, are seen in the specimen illustrated by figure 27, plate LXXV. The medium-sized specimen of figure 19 of the same plate is interesting as showing, besides parts of the body, a considerable part of the slender antennæ, and something of the crushed head.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan.

Etoblattania? sp. Pl. LXXII, fig. 3.

The large nymph illustrated by figure 3, plate LXXII, has a very bulky abdomen with unusually prominent epimera and

Schizoblattina minor sp. nov.

Subcostal area well developed, broad at the base, reaching somewhat beyond the middle of the wing. Branches few, mostly simple. Radius dividing about the middle of the wing, the upper division simple, the lower dividing once or twice, the branches falling a little short of the apex. The media divides before reaching the middle of the wing, the branches running apparently to the apex and to the inner border. The cubitus branches early and is of moderate extent. Estimated length of tegmina, 13 or 14 mm.; breadth, 5 or 6 mm.

The species is much smaller and the veins of the wing fewer than those of the type of the genus. The one specimen of the species found is contained in a fine-grained clay, which, unfortunately, on account of being near the surface, has become much water-soaked, so that the impression of the wing is dim and the cross-veins if present fail to appear.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Type, No. 161, University of Kansas collection.

Schizoblattina schucherti sp. nov. Pl. LXX, fig. 7.

The Yale collection contains a third species of this genus. The humeral angle, as is usual with the genus, is square and very prominent. The subcostal area is broad, but short, reaching hardly half the length of the wing. Four branches arise from the subcosta, the first three of which are forked in the type specimen. The radius gives off its first branch at the termination of the basal fourth of the wing. The radial area probably reaches to the apex. The median area is narrow. The first branch is given off opposite the end of the anal area and is twice forked. Two or three other forked branches are given off. The main vein is strongly curved and meets the inner border only a little beyond the middle of the wing. The cubitus is short, curved, and runs along parallel to the media, meeting the inner border just beyond the middle line of the wing. The cubital branches are heavy but flexuous. The first two end on the anal furrow. The following are simple and run to the inner border. Cross-veins are fewer than in the type of the genus. They are seen best developed in the central part of the wing, uniting the branches of the media. The anal area is unknown. Length estimated at 11 to 12 mm.; breadth, 4 to 4½ mm.

The species differs from *S. multinervia* in the fewer

branches of the subcosta and fewer cross-veins, and from both *S. multinervia* and *S. minor* in the cubitus, in which the dichotomous character is lacking, while inferior branches are given off.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Type, No. 72, Yale collection.

Spiloblattina.

Scudder, Proc. Acad. Nat. Sci. Phila., p. 35, 1885.

The genus *Spiloblattina* was based originally on material from Fairplay, Colo. The essential characters of the genus are the wide divergence of the radius and media and of the media and cubitus and their subsequent convergence to enclose an elongate area, the stigma. The tegmina are thin and marked with light and dark areas, while dark bands accompany the veins. The hind wings, and body as well, are likewise variegated, showing light and dark areas. It appears also from material from the Kansas Coal Measures that the ovipositor of the female is much smaller than that of *Etoblattina*, projecting but little beyond the end of the abdomen. The Fairplay deposits from which the genus was described are of doubtful position, having been referred by some to the Permian, by others to the Triassic. In the Kansas deposits the genus is seen to extend as far down as the Coal Measures. It is found also, according to the writer's determinations, in the Coal Measures of Ohio, Scudder's species *Etoblattina maledicta* being referred, as seen below, to this genus.

Spiloblattina maledicta. Pl. LXXVI, figs. 26, 27; pl. LXXVII, figs. 6, 8; pl. LXXX, fig. 1.

Etoblattina maledicta Scudder, Bull. U. S. Geol. Surv., No. 124, p. 83, pl. 6, figs. 1-3, 1895.

Etoblattina benedicta Scudder, *ibid.*, p. 84, pl. 5, figs. 14, 15.

Spiloblattina maledicta Scudder sp. Sellards, Amer. Jour. Sci., vol. 18, pp. 214-216, text figs. 26, 27; pl. 1, figs. 5, 6, 10, 1904.

Tegmina narrow, two and one-half times as long as broad, costal border slightly arched, inner border nearly straight; tegmina broadest at the extremity of the anal area, apex obtuse. Subcostal area narrow, extending a little beyond the middle of the tegmina; branches mostly simple and oblique. The radius reaches nearly to the apex. The first branch is given off at about the extremity of the basal third, sometimes as early as the end of the basal fourth, and is usually twice forked. Three or four other simple or deeply forked branches pass to the border. The media gives off its first branch some-

what beyond the middle. The main vein and its branches fill the apex. The cubitus varies in extent, either reaching well onto the apical margin, its greatest extent being obtained by an outward curve near the termination, or, lacking the curve, ending short of the apical margin. The first five or six branches are straight, mostly simple, and parallel; the others are more oblique, not uniform in number, curved and sometimes forked. The anal area extends approximately to the end of the basal fourth, is clearly marked off, and has six or seven mostly simple veins. The main veins of the wing originate close together somewhat above the middle of the base. The veins diverge in the central part, enclosing elongate light-colored areas. The tegmina are delicate and thin, the veins thin, although appearing heavy in places because of the dark-colored bands accompanying them. The alternate dark and light areas give the wing a variegated appearance. A dark band extends along the costal border, obscuring the tips of the veins. Similar bands accompany the radius, media and cubitus. Light areas occur between the interspaces of the main veins, as well as between some of the principal branches. Two conspicuous, large, light spots occur in the apical part of the wing. The agreement with the types of the species is very close. The two light spots on the apical part of the tegmina are not described for the type, probably because the apex was not well preserved.

The hind wings are thin and ovate in shape. The costa is submarginal, straight and simple, reaching about one-third the length of the wing. The subcosta lies at the bottom of the subcostal fold, gives off a few oblique, short superior branches beyond the termination of the costa, and reaches somewhat beyond the middle of the wing. The radius reaches nearly to the apex and gives off one to three very oblique simple or forked branches. The media has four or five superior branches which fill the apex. The media continues independent almost or quite to the base. The cubital area is well developed, the branches very oblique, simple, straight, parallel. The first anal vein is simple. Beyond the first anal are seen a few simple or forked veins. Eleven hind wings of this species have been obtained, one in direct connection with the tegmina. The hind wing is of even thinner texture than the front, and has, like the front wing, light and dark areas. A dark area extends

along the costal border, and dark bands accompany some of the veins.

A few nymphs having light and dark areas on the body occur in association with the wings, and are without doubt of this species. The abdomen is slender. The sterna are pointed at the posterior corner instead of rounded as in *Etoblattina*. The ovipositor also, as shown by these specimens, is much shorter, projecting but little beyond the abdomen. Length of tegmina, 22 to 25 mm.; width, 8 to 9 mm. Hind wing, 16 to 18 mm. long, 8 to 9 mm. wide.

In the original description of *E. benedicta*, Scudder expressed doubt as to its specific separation from *E. maledicta*. The differences which seemed to distinguish the two forms were the more arched costal border of *E. benedicta*, the lesser extent of the cubital area, and the approximation in the point of origin of the two radial branches. More than forty-five tegmina of this species are at hand for comparison. Camera lucida sketches of numerous wings show that while those with a short cubitus have, as a rule, a more arched border, there is an almost continuous series between with no break sufficient to serve as a specific character. Figures 26 and 27, plate 76, show the extreme limits in the extent of the cubitus, the two wings illustrated corresponding closely to the types of the two species. In one the cubitus falls decidedly short of the apical margin, while in the other it extends by an outward curve and more numerous branches well onto this border. Other specimens show that the cubitus is variable in extent, and individuals can be found so nearly intermediate that a specific separation can hardly be sustained on this character. The third distinction given, the approximation in the point of origin of the first and second radial branches, is not constant. The large number of specimens of this species at hand allows a closer study of individual variation of the veins of the tegmina than has been possible heretofore in any Paleozoic species. The results emphasize the necessity of allowing for a certain amount of individual variation among the accessory branches of the wing, and to some extent in the relative extent of the main divisions.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Nos. 4, 17, 18, 19, 29, 37, 41, 47, 48, 50, 54, 56, 60, 61, 64, 66, 70, 72, 75, 79, 85, 92, 93, 101, 105, 107, 112, 113, 121, 122, 124, 126, 132, 133, 137, 138, 139, 145, 164,

166, 169, 177, 183, 186, 208, 212, 227, University of Kansas collection; Nos. 26, 30, 32, 38, 43, 55, author's collection.

Spiloblattina lineata sp. nov. Pl. LXXXI, fig. 1.

Tegmina very slender, three times as long as broad, scarcely at all curved, outer and inner margins parallel; apex obtuse, placed somewhat above the middle line of the wing and pointed slightly upward. Subcostal area narrow, extending about two-fifths the length of the wing, and sending several nearly straight, parallel, oblique branches to the costal border. Radius branched near the base, about opposite the middle of the anal area; six branches in the type specimens are given off, the first five of which are forked. The radial area reaches just to the apex. The media is simple until beyond the middle of the wing. It gives off four branches, the first three being compound. The cubitus is sinuous and extends about three-fourths the length of the inner border. The branches are simple, arched, parallel, and unusually strong, especially those towards the distal end of the cubitus. The anal area is rather long and narrow, and is well marked. It is provided with about seven simple veins. The sixth and seventh anal veins of the type are united throughout the distal third of their length, presenting in this respect an anomalous condition, and doubtless indicating a process of reduction in the number of anal veins. Length of wing, 24 mm.; breadth, 7 mm.

The tegmina is straighter and more slender than that of *S. maledicta;* the first radial branch originates earlier, the anal area is more narrow and the anal veins more numerous. The distribution of the radiomedian and mediocubital interspaces is similar to that of *S. maledicta.* The branches of the cubital, however, particularly the distal ones, are noticeably stronger. Specimen No. 18, University of Kansas collection, probably belongs to this species. The tegmina is slender. The first two cubital branches are united in their distal part.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Type, No. 16, University of Kansas collection.

Spiloblattina curvata sp. nov. Pl. LXXX, fig. 3.

Tegmina strongly arched, elongate. Subcostal area broad; branches from the subcosta mostly simple, oblique. Radius strongly curved at the base. The first branch is given off opposite or back of the end of the anal area. The media is

also curved and lies close to the radius. Its first branch is given off beyond the middle of the wing. The cubitus, like the media and radius, is very strongly arched and comes to the inner border only a little beyond the middle of the wing. Its five or six branches are simple, parallel, very oblique. The anal area is elongate-pointed behind. Of the six or seven veins the third in the type specimen is forked at a wide angle. The type specimen of this species has suffered distortion as it lies in the matrix, thus accentuating the natural curve of the wing. Estimated length of the wing, 23 to 25 mm.; breadth, 8 mm.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Type, No. 56, University of Kansas collection.

Spiloblattina laxa sp. nov.

Tegmina thin, uniformly rounded. Subcostal area narrow, but long, extending much beyond the middle of the wing. Subcostal branches several, simple, oblique. Radius divided near the middle of the wing, the two divisions again forked and running to the border above the apex. The branches of the media fill the apex. The tip only of the cubitus is seen in the type specimen. It extends well onto the apical border. Its distal branches, like those of *S. maledicta,* are very oblique. The broad, thin tegmina have much the appearance of hind wings, lacking entirely the rigidity that usually characterizes tegmina. Length of tegmina estimated at 17 to 19 mm.; breadth, 7 or 8 mm.

At the same locality is found a hind wing which, from its lax apearance and resemblances in venation, not improbably belongs with the front wing. The subcosta of this hind wing is also long, reaching two-thirds the length of the wing. The radius is very similar to the radius of the front wing, divides early, both divisions again soon branched. The media occupies more area than the radius. Its first branch is compound and runs to the apex. The other branches end on the inner border. The cubitus is short and weak and has only about three thin branches. The first anal vein is forked. The anal area beyond is crumpled up in the type specimen—apparently there are a few longitudinal veins. A dark area similar to that of the tegmina accompanies the subcostal. The hind wing as a whole

is flat and weak. Length, probably 17 or 18 mm.; width, 8½ to 9 mm.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Type, No. 171, University of Kansas collection.

Hænoblattina gn. nov.

Medium-sized, thin-winged cockroaches. Veins of the tegmina few, branching at wide angles.

The two species referred to this genus are in important respects unlike any of the associated forms. The tegmina lack the strongly arched costal border of most cockroaches. The radius, media and cubitus divide apparently by dichotomy rather than by the usual method of giving off branches. The anal area of the type species apparently gives off from the first anal vein one or two branches which run to the anal furrow. The cubital vein is not well preserved but appears to resemble closely the typical cubitus as seen in many insects other than cockroaches, divided into two parts, each of which are again branched.

Hænoblattina tenuis sp. nov. Pl. LXXI, fig. 1.

Cockroaches of medium size with thin, broad, few-veined wings. Tegmina almost three times as long as broad. Costal and inner borders nearly straight, apical border thin and wavy, apex obtusely rounded. Wing broadest back of the middle. Subcostal area narrow, the main vein straight, hardly reaching the middle. Branches few and oblique. The radius extends to and occupies part of the apical border. A few superior branches are given off, the first of which arises near the end of the anal area. An inferior branch also arises from the radius in front of the middle, and continues straight and simple through the middle of the wing to the apical border. The first median branch is given off somewhat in advance of the middle, soon branches, the upper division being again forked. The main vein continues in a sinuous course to the inner border, giving off about two other branches. The cubital area is narrow and has only about three oblique branches. The anal area is long, but narrow, and has only a few veins. Two thin branches seem to take their origin from the first anal vein and run toward the anal furrow. The basal part of the wing has suffered from lateral crushing, which makes it ap-

pear unnaturally narrow. The species differs from the following in greater length in proportion to its width, and in a different distribution of its secondary veins. Length of tegmina, 29 mm.; width, 10 mm.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Type, No. 125, University of Kansas collection.

Hænoblattina rarinervis sp. nov. Pl. LXXI, fig. 2.

Medium-sized cockroaches with thin, few-veined wings. Tegmina a little more than twice as long as broad; costal border but gently arched, inner border nearly straight. Subcosta falling short of the middle of the wing, and with a few oblique branches. The radius extends to the apex, occupying with the subcostal area about two-fifths of the wing. The first branch is given off opposite the extremity of the anal area and is compound. One other branch, also twice forked, arises beyond the middle of the wing. The media branches first just before the middle, its divisions filling the apex. The cubitus extends approximately three-fourths the length of the wing. The first branch is forked and there are one or two other simple branches. The anal area is well marked and has five simple veins. The University of Kansas collection contains a second specimen, No. 45*a*, which apparently agrees closely with the type. The radius has two branches, both of which are forked. The two divisions of the media soon branch again as in the type, and the cubitus is similar in extent. Length of tegmina, 25 mm.; width, 11½ mm.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Type, No. 147, University of Kansas collection.

Puknoblattina gn. nov.

Small cockroaches with elongate compact wings. The radius and media united at the base.

Puknoblattina compacta sp. nov. Pl. LXXIII, figs. 5, 6; pl. LXXIV, fig. 4.

Wings elongate, slightly arched, borders nearly parallel; wing of approximately equal width from base to rounded apex. The subcosta reaches to the middle of the wing, and is provided with numerous simple branches. Radius and media fused throughout the basal one-fourth of the wing; radius

reaching to near the apex and giving off five or six simple or forked branches, the first of which originates beyond the basal third of the wing. The media and its branches fill the apex. The branches are simple, long, parallel. The cubitus is long, reaching along the inner border almost to the apex. Its numerous branches are mostly simple. The anal area is well marked off, concave, and has six to nine simple veins. Length of tegmina, 9 to 11 mm.; width, 3 to 3½ mm.

Six specimens of this species have been found. The species is easily recognized by the small, compact tegmina with numerous veins. There is considerable variation among the several specimens referred to the species, and possibly more than one species is represented. Nos. 850 and 1011 are smaller and have shorter subcosta and more numerous veins.

Formation and locality: Wellington shales, Banner City; Nos. 123, 476, 850, 1011, 770, 463, 656, 1008, author's collection.

Puknoblattina curvata sp. n. Pl. LXXIII, fig. 3.

Wings strongly arched. The subcosta reaches to the middle of the wing and is supplied with several branches. The radius reaches nearly to the apex and has numerous superior branches. The media curves downward strongly and has strong parallel branches. The cubitus is curved and has strong parallel branches.

Formation and locality: Wellington shales, Banner City.

NYMPHS OF COCKROACHES.

The most abundant type of nymph cockroaches at the Lawrence locality is the form previously described (Amer. Jour. Sci., vol. 18, p. 131, text figs. 17 to 21, 1904) under the term *Etoblattina juvenis*. The abdomen of this type is large and broad, the terga have well-developed free edges, and the sterna have rounded corners. Two instructive individuals of the species lying on a small slab are shown in their relative positions in figure 7, plate LXXVI. The dorsal integument of the nymph at the right of the figure is broken down the center, thus exposing the basal elements of the legs. The basal part of the ovipositor, 9 mm. long, is preserved in place on this specimen. Parts of the body are scattered about on the slab. Detached terga, with their pointed edges, and one of the sterna, with rounded edges, are seen lying between the two nymphs. The nymph on the left of the figure is more nearly

entire. The head is displaced to the right of the pronotum. The antennæ are very well preserved. On the pronotum is seen a circular mark which seems to be characteristic of the species. Traces of the venation are evident, the cubitus and its branches, as is usual among nymphs, being the first to appear. Parts of the legs are exposed at the sides of the body. The tibia is spinous and the tarsus apparently long. The pointed free edges of the terga are evident. The cerci, although incomplete, are unusually long. A considerable number of specimens of this general type and in various stages of development have been obtained from the Le Roy shales. During the early stages the corners of the pronotum are rounded. As the nymph approaches maturity the corners become more pointed and the pronotum broader in proportion to its width. The cubitus is the first of the veins to appear in the developing wing, and in some of the larger specimens most of the veins of this area can be seen.

The first three or four terga and sterna of the specimen illustrated by figure 18, plate LXXV, are seen in place, the sterna showing as impressions through the terga. In the wings of this specimen traces of the venation are evident, as is also the thickened spot at the base, which marks the point at which the articulation of the wing with the body is found. The detached wing of figure 20 of the same plate is from a more mature individual, and traces of all of the main veins are to be seen. The cubitus especially is well developed. Two or three anal veins are to be seen also, although the anal area is not as yet distinctly marked off. The detached wing photographed, figure 3, plate LXXXII, has reached about the same stage of development and shows a similar distribution of veins. The trochanter, femur and tibia of one leg, with a detached tergum at the side, are seen in the specimen illustrated by figure 27, plate LXXV. The medium-sized specimen of figure 19 of the same plate is interesting as showing, besides parts of the body, a considerable part of the slender antennæ, and something of the crushed head.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan.

Etoblattania? sp. Pl. LXXII, fig. 3.

The large nymph illustrated by figure 3, plate LXXII, has a very bulky abdomen with unusually prominent epimera and

with sterna more pointed than are those of the *E. juvenis* type. The legs are strong, as indicated by the femur. The wings are long in proportion to their width. Traces only of the wing venation have appeared. It is quite possible that these large nymphs are the young of the large species described as *Etoblattina scudderi.*

Spiloblattina sp. Pl. LXXII, fig. 1.

A few specimens from the Le Roy shales are apparently referable to the genus *Spiloblattina.* These are of interest on account of the light they throw on the body structure of this genus. The ovipositor is preserved on one of these nymphs and is seen to be much shorter than is the ovipositor of any of the *Etoblattina* species. It is slender and projects only slightly beyond the end of the abdomen. The body as seen in these specimens is, like the wings, light-colored, in contrast to the usual brown or dark color of *Etoblattina.*

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan.

The generic reference of the small nymph of figure 23, plate LXXV, is in doubt. The abdomen has been slightly crushed, but the ten segments can be made out. A few of the sterna are seen in outline through the terga and are pointed at their posterior corners. A tibia, tarsus, and part of a femur lie in front of the pronotum. The number of segments of the tarsus cannot be made out, but the claw terminating the foot is preserved. A second specimen of about the same size is illustrated by figure 2, plate LXXII.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan.

The rounded pronotum of figure 24, plate LXXV, represents evidently still another type of nymph. Its generic reference is in doubt. The pronotum of *Schizoblattina* is unknown, while some species of *Etoblattina* have during their early stages a circular pronotum.

No less than twelve specific types of hind wings are recognized in the collections; six from the Coal Measures and six from the Permian, each represented by one or more well-preserved specimens. Such of these as can be connected with their respective front wings have been described with the tegmina. Those which are not associated with the front wings are described briefly.

Etoblattina sp. Pl. LXXVI, fig. 5; pl. LXXVII, fig. 3.

A type of hind wing very abundant in the Le Roy shales is that shown in figure 5, plate LXXVI. There are nine specimens of the species, all conforming closely to a common type. The wings are uniformly ovate. The inner border is full and rounded. The costa is straight, simple, and reaches about one-fourth the length of the wing. The subcostal area, as is usual in the hind wing, is narrow and of slight extent. A few thin superior branches are given off from the main vein beyond the extremity of the costa. The radial area reaches nearly to the apex and has about four forked branches. At the base it unites with the subcosta. The median area is large and fills the apex. The cubitus has many oblique, simple, parallel branches. The few anal veins are parallel and usually simple. The first anal vein is more strongly marked but otherwise similar to the succeeding veins. The wings are of a light brownish color.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Nos. 42, 104, 114, 118, 123, 135, 167, 173, and 189, University of Kansas collection.

Etoblattina sp. Pl. LXXVI, fig. 6; pl. LXXVII, figs. 1, 2, 5.

Another and more advanced type is that seen in figure 6 of plate LXXVI and figures 1, 2 and 5 of plate LXXVII. The wing is contracted at the base and has a narrow attachment. The costal border near the base is quite concave, but beyond the middle becomes again convex. The subcosta, radius and media are united for some distance from the base. The first to separate is the media, which occupies a rather narrow space through the central part of the wing, branching first before reaching the middle of the wing, its divisions going to the apex. The radius separates from the subcosta 5 or 6 mm. from the base, and with its branches reaches almost to the apex. The subcosta has only a few thin superior branches. The cubitus has the typical, mostly simple, very oblique veins. At the base the cubitus lies very close to but does not actually unite with the stem of the veins above. The vein occupying the anal furrow is in this species once forked. The second anal is seen to give off two or three simple or forked branches. The anal area beyond the second anal vein is unknown. Length of wing, estimated, 17 mm.; width, 9 or 10 mm.

Formation and locality: Le Roy shales, Upper Coal Meas-

ures, Lawrence, Kan. Figured specimens Nos. 95 and 62, University of Kansas collection; No. 58 of the University collection is also referred to this species.

Etoblattina sp.

The wings of this species have a brownish color as preserved. The subcosta has two or three simple branches beyond the end of the costa. The radius is united with the subcosta at the base, and reaches almost to the apex of the wing. Its three or four branches are oblique and forked. The media gives off branches early and fills the apex of the wing. At the base it runs close to and apparently unites with the radius. A considerable interspace is seen between the media and cubitus. This area is elongate, broadest in the middle, partially closed at the basal and apical ends. The cubitus is a strong vein, and reaches well onto the apical border. Its five or six branches are very oblique, simple or once forked. The anal area of this species is unknown. It is probable, from the shape of that part of the wing preserved and from its resemblance to the species described above, that the wing has an ovate form with moderately expanded anal area. Length of wing, 17 or 18 mm.; breadth, 9 or 10 mm.

This species, as well as the one last described, can with little hesitation be referred to the genus *Etoblattina*. The brown color, as well as the size of the wing, suggest a possible connection with *E. fulva* described above.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan. Figured specimens Nos. 40 and 123, University of Kansas collection.

Etoblattina sp.? Pl. LXXX, fig. 4.

The hind wing shown in photograph, figure 4, plate LXXX, is probably of the genus *Etoblattina*, although it is light-colored, in which respect it suggests the genus *Spiloblattina*. The radius is strong, branches early, its divisions reaching almost to the apex. The median area is slender, branches first opposite the second branch of the radius, its divisions running to the inner border. At the base it runs close to and probably unites with the radius. The cubitus is a strong vein. Its four or five lower branches are oblique and parallel. The first anal vein is deeply impressed and strong to the base. The area beyond the first anal is unknown.

Formation and locality: Le Roy shales, Upper Coal Measures, Lawrence, Kan.

Etoblattina sp. Pl. LXXIV, fig. 9.

Dorsal border concave near the base, arched convex farther out, apex rounded; inner border full; radius reaching almost to the tip, with four or five superior branches; media with inferior branches filling the apex; cubitus with six or seven closely placed simple branches; anal furrow nearly straight. This species conforms closely to the typical *Etoblattina* type of hind wing and more nearly resembles the Coal Measure hind wings than do any of the other types described from the Permian. The anal area is incomplete, the inner part only being preserved. Length of wing, 10 mm.; width, 5 mm.

Formation and locality: Wellington shales, Banner City. Type, No. 769, author's collection.

Etoblattina sp. Pl. LXXIV, fig. 7.

A much larger species is indicated by the basal part of a single hind wing. The part preserved is 11 mm. long. The full length of the wing was probably not less than 13 to 14 mm. The wing is strong and all of the veins deeply impressed. The subcosta lies at the top of a sharp fold. The veins are closely crowded at the base, the subcosta, radius and media lying very close together. The first anal vein gives off three branches, the first two of which are forked. It is possible that this hind wing belongs with the associated large tegmina of *Etoblattina permiana.*

Formation and locality: Wellington shales, Banner City. No. 486, writer's collection.

Etoblattina sp. Pl. LXXIV, fig. 1.

Hind wing of medium-sized cockroach; costa submarginal; subcosta with two or three branches; radius reaching to the rounded tip; first branch of the media originating early, twice forked, second branch with two inferior divisions; cubitus and branches lax, first cubital vein forked; vein occupying the anal furrow once forked; first anal vein giving off three branches, the first of which is twice forked; wing broad, apex obtuse, veins not closely crowded at the base. The cubitus of this species is unusually lax, and the medius is differently branched from any of the associated species.

Formation and locality: Wellington shales, Banner City. No. 1002, author's collection.

Etoblattina? sp. Pl. LXXIV, fig. 3.

The species most common in the Permian is referred with some doubt to *Etoblattina*. There are no less than six recognizable specimens of this species. The costal border is less strongly arched than is that of the species last described. The subcosta is submarginal and short, reaching hardly to the middle of the wing. The radius is a strong vein. Its basal branch is given off early and gives rise to two or three branches beyond the subcosta. The third radial branch has also usually two or three branches. The media occupies a smaller area than does the radius. The cubital vein gives about four simple, curved veins. The anal furrow is well marked. The first anal vein gives off three branches, one of which is forked. A second anal furrow runs through the middle of the anal area, dividing it into two approximately equal parts. The branches from the first anal vein end on this furrow. Beyond the furrow the branches are once more longitudinal, and run parallel to the furrow.

Formation and locality: Wellington shales, Banner City.

Etoblattina sp.

Closely related to the wing last described is that of a specimen having a similar fold with the veins of the anal area ending on the anal furrow, and with the veins beyond the furrow again parallel. It differs essentially in the more numerous branches of the first anal and especially in the presence of reticulated cross-veins connecting these branches. The veins beyond the fold are more distinctly seen here than elsewhere. The first strong vein divides not far from the base. The inner of these divisions soon divides, and one of these secondary branches again subdivides. All run nearly parallel to the furrow, and all end on the inner border. This specimen is illustrated in *Popular Science Monthly*, March, 1906.

Formation and locality: Wellington shales, Banner City.

Puknoblattina compacta?

The association of these wings with *Puknoblattina* is based on their agreement in size and the fact that no other small cockroach has been found present at the locality. The costal border of the wing is very slightly rounded. The subcostal area is narrow and extends to or somewhat beyond the middle of the wing. The radial vein is strong and sends three or four branches to the costal border. The media sends about

three longitudinal, simple or forked branches which reach the border at or below the apex. The cubital vein gives off four or five simple, nearly straight branches. Only a part of the anal area is preserved. That it presents the structure shown by other hind wings is, however, indicated by the small part preserved. The first anal vein is seen to give off two lateral branches. The parts of the wings preserved indicate a length of 8½ to 9 mm.; breadth back of the anal area not less than 4 mm.

Formation and locality: Wellington shales, Banner City.

Puknoblattina sp. Pl. LXXIV, figs. 5, 8.

A very small hind wing, No. 472, represents a second but closely related species. The distribution of the vein areas is very similar to that of the species just described. The costa is submarginal and extends nearly half the length of the wing. The subcosta extends somewhat beyond the middle of the wing and gives off at least one branch. The radius, as in the last, reaches to the apex, having three superior branches, the first of which is forked. The median area is, as in the last species, well developed, having four superior branches, the second of which is forked. The origin of the main branch is obscure but is apparently fused for some distance with the radius. Cubitus has three branches. Anal area unknown. Length of wing, 6 mm.; width at the extremity of the median area, 2 mm.

Formation and locality: Wellington shales, Banner City.

LIST OF SPECIES OF COCKROACHES OF THE KANSAS COAL MEASURES AND PERMIAN.

Coal Measures species.

Mylacris latissima sp. nov.
Promylacris radialis sp. nov.
Etoblattina scudderi sp. nov.
Etoblattina obscura sp. nov.
Etoblattina savagi sp. nov.
Etoblattina brevi-cubitalis sp. nov.
Etoblattina fulva sp. nov.
Etoblattina occidentalis Scudder.
Etoblattina coriacea Sellards.
Archimylacris recta sp. nov.
Spiloblattina maledicta Scudder sp.
Spiloblattina lineata sp. nov.
Spiloblattina laxa sp. nov.
Spiloblattina curvata sp. nov.
Gerablattina arcuata Sellards.
Hænoblattina tenuis sp. nov.
Hænoblattina rarinervis sp. nov.
Schizoblattina multinervia Sellards.
Schizoblattina minor sp. nov.
Schizoblattina schucherti sp. nov.
Etoblattina juvenis Sellards.
Etoblattina sp. (based on nymph).
Spiloblattina sp. (based on nymph).
Genus undetermined (based on nymph).
Etoblattina sp. (hind wing).
Etoblattina sp. (hind wing).
Etoblattina sp. (hind wing).
Etoblattina sp.? (hind wing).

Permian genera and species.

Etoblattina permiana sp. nov.
Etoblattina curta sp. nov.
Etoblattina pecta sp. nov.
Etoblattina sp. (hind wing).
Etoblattina sp. (hind wing).
Etoblattina sp. (hind wing).
Etoblattina sp. (hind wing).
Etoblattina sp. (hind wing).
Puknoblattina compacta sp. nov.
Puknoblattina sp. (hind wing).
Puknoblattina curvata sp. nov.

GEOLOGICAL RELATIONS OF THE KANSAS UPPER PALEOZOIC COCKROACHES.

Le Roy Shales.—Of the eight genera of cockroaches recognized in the Le Roy shales, three, *Mylacris, Promylacris,* and *Archimylacris,* are, so far as known, confined to the Coal Measures, and are best developed in the Lower and Middle Coal Measures. Two of the eight genera, *Etoblattina* and *Gerablattina,* are known to occur in both the Coal Measures and the Permian. One genus, *Spiloblattina,* has not previously been recorded as occurring in deposits as old as the Coal Measures. Some specimens from the Ohio Coal Measures previously referred to *Etoblattina* are, however, placed in *Spiloblattina.* The remaining two genera, *Schizoblattina* and *Hænoblattina,* are described as new from these deposits. To *Schizoblattina, however, is referred a species, Neorthoblattina albolineata* of Scudder, previously described from Fairplay, Colo. (Supposed Trias or Permian.)

It is thus seen that, so far as an enumeration of genera is concerned, there is in the Le Roy shales, along with typical Coal Measure forms, a mingling of genera which reached their greatest development in early Coal Measures, with others taking their origin during late Coal Measure time and reaching into the Permian. The three older genera are represented by a single species each. *Etoblattina,* which is recognized as reaching its greatest development during Upper Coal Measure and Permian time, is represented by seven species, while *Spiloblattina,* an Upper Coal Measure-Permian genus, has four species. Of the two new genera, *Hænoblattina* is represented by two species and *Schizoblattina* by three. By far the greater number of individuals belong to *Etoblattina* and *Spiloblattina.* The species obtained from the Le Roy are with two exceptions new and are of types commonly found in Upper Coal Measure deposits.

The Wellington Shales.—Two genera are recognized in the

Wellington shales, *Etoblattina,* continuing over from the Coal Measures, and *Puknoblattina,* a new genus. The ten species found in the Wellington are all new. They are in general much smaller than the Coal Measure species, while the compact wings of the species of the genus *Puknoblattina* is suggestive of an approach to Mesozoic cockroaches. Cockroaches were apparently by no means so abundant relatively during Permian time as they were during Coal Measure time. The number of cockroach specimens obtained from Coal Measure localities are usually found to exceed all other insects combined. In the Wellington shales the cockroaches are much in the minority. A collection of something over 2000 insect specimens from this formation made by the writer is found to contain only about 70 cockroaches. Of the associated insects the orders Odonata and Plectoptera have been described by the writer in the American Journal of Science (vol. 22, pp. 249-258, 1906; vol. 23, pp. 345-355, 1907). A description of the remaining material obtained from the Permian has not yet been published. It may be said, however, that the insects consist largely of new types and that the fauna represents a distinct advance over the Coal Measure insect fauna.[307]

307. Since the above was written representatives have been described of the Megasecoptera, Oryctoblattinidæ, and Protorthoptera. Amer. Journ. Sci., vol. XXVII, pp. 151-178, 1907.

EXPLANATION OF PLATES.

PLATE LXX.

FIG. 1.—*Etoblattina occidentalis* Scudder. University of Kansas collection, No. 146. Three times natural size.

FIG. 2.—*Etoblattina occidentalis* Scudder. University of Kansas collection, No. 8. Three times natural size.

FIG. 3.—*Gerablattina arctuata* Sellards. University of Kansas collection, No. 170. Two and one-half times natural size.

FIG. 4.—*Etoblattina fulva* sp. n. University of Kansas collection, No. 130. Two and one-half times natural size.

FIG. 5.—*Etoblattina obscura* sp. n. University of Kansas collection, No. 149. Two and one-half times natural size.

FIG. 6.—*Etoblattina fulva* sp. n. University of Kansas collection. Twice natural size.

FIG. 7.—*Schizoblattina schucherti* sp. n. Yale Museum; No. 72. Enlarged.

FIG. 8.—*Promylacris radialis* sp. n. University of Kansas collection, No. 88. Two and one-half times natural size.

FIG. 9.—*Etoblattina fulva* sp. n. University of Kansas collection, No. 142. Twice natural size.

PLATE LXXI.

FIG. 1.—*Hænoblattina tenuis* sp. n. University of Kansas collection, No. 125. Two and one-half times natural size.

FIG. 2.—*Hænoblattina rarinervis* sp. n. University of Kansas collection, No. 147. Two and one-half times natural size.

FIG. 3.—*Etoblattina scudderi* Sellards.

FIG. 4.—*Etoblattina savagi* sp. n. University of Kansas collection, No. 57. Three times natural size.

FIG. 5.—*Mylacris latissima* sp. n. University of Kansas collection, No. 36. Two and one-half times natural size.

FIG. 6.—*Etoblattina scudderi* Sellards.

PLATE LXXII.

FIG. 1.—*Spiloblattina* sp. End of abdomen, with ovipositor. Author's collection, No. 43.

FIG. 2.—Nymph cockroach. University of Kansas collection, No. 229. Six times natural size.

FIG. 3.—Large nymph. *Etoblattina*(?). Author's collection, No. 46.

FIG. 4.—Detached wing, probably of a nymph. University of Kansas collection, No. 211. Six times natural size.

PLATE LXXIII.

FIG. 1.—*Etoblattina curta* sp. n. Author's collection, No. 8. Six times natural size.

FIG. 2.—*Etoblattina pecta* sp. n. Author's collection, No. 1013. Six times natural size.

FIG. 3.—*Puknoblattina curvata* sp. n. Author's collection. Six times natural size. No. 850.

FIG. 4.—*Etoblattina curta* sp. n. Author's collection, No. 111. Six times natural size.

FIG. 5.—*Puknoblattina compacta* sp. n. Author's collection. Six times natural size.

FIG. 6.—Same species. Author's collection. Six times natural size.

FIG. 7.—*Puknoblattina* sp. Author's collection, No. 472. Enlarged.

FIG. 8.—*Etoblattina* sp. Author's collection, No. 1006.

All from the Wellington shales (Permian). Banner City.

PLATE LXXIV.

FIG. 1.—*Etoblattina* sp. Hind wing. Author's collection, No. 1002. Six times natural size.

FIG. 2.—*Etoblattina* sp. Hind wing. Author's collection, No. 1003. Six times natural size.

FIG. 3.—*Etoblattina* sp. Hind wing. Author's collection, No. 769. Six times natural size.

FIG. 4.—*Puknoblattina compacta*(?) sp. n. Author's collection, No. 659. Six times natural size.

FIG. 5.—*Puknoblattina* sp. Hind wing. Author's collection, No. 1012. Six times natural size.

FIG. 6.—Nymph of cockroach? Author's collection, No. 209. Six times natural size.

FIG. 7.—*Etoblattina* sp. Hind wing. Author's collection, No. 486. Six times natural size.

FIG. 8.—Counterpart of specimen shown in figure 5.

FIG. 9.—*Etoblattina* sp. Author's collection. Six times natural size.

All from the Wellington shales, at Banner City.

PLATE LXXV.

FIG. 18.—*Etoblattina juvenis* Sellards. A nymph, of which the thorax and a part of the abdomen are preserved. The abdominal sterna are seen in the outline through the terga.

FIG. 24.—Pronotum of small, probably adult, cockroach.

FIG. 25.—Egg-case of cockroaches. From the Le Roy shales.

FIG. 22.—*Spiloblattina.* Part of abdomen, in which are seen indications of color areas resembling those of *Spiloblattina*, to which genus the specimen is provisionally referred.

FIG. 23.—A small nymph, genus undetermined.

FIG. 19.—*E. juvenis* Sellards. A nymph of which a considerable part of the long antennæ and the outline of the head are preserved. The two parts of the pronotum are separated. The absence of spines on the tibia is probably due to imperfect preservation.

FIG. 20.—*E. juvenis* Sellards. One wing and half of pronotum of nearly mature nymph.

FIG. 27.—Trochanter, femur, and one abdominal tergum of nymph.

All figures are twice natural size. Original of figures 18 and 19 in the University of Kansas collection; all others in the writer's collection. All are from the Upper Coal Measures. Figure 23 is from Deer Creek, twelve miles southwest of Lawrence; others are from Lawrence, Kan.

PLATE LXXVI.

FIG. 26.—*Spiloblattina maledicta* Scudder. Form with arch costal border and short cubitus. Original in University of Kansas Museum. Twice natural size.

FIG. 28.—*Schizoblattina multinervia* Sellards. Twice natural size.

FIG. 27.—*Spiloblattina maledicta* Scudder, sp. Typical wing with extended cubitus. Original in University of Kansas Museum. Twice natural size.

FIG. 29.—*Etoblattina coriacea* Sellards. Twice natural size. Anal area restored from the obverse side of the same specimen. Original in University of Kansas Museum.

FIG. 5.—*Etoblattina* sp. Original in the University of Kansas Museum.

FIG. 6.—*Etoblattina* sp. Hind wing.

FIG. 7.—*Etoblattina juvenis* Sellards. Natural size. Two specimens lying near each other on the same slab. The nymph on the left shows a considerable part of the cerci, which in this specimen are very long. Both have the legs more or less completely preserved. As a result of crushing, the integument of the nymph at the right has split along the dorsal line, and, spreading laterally, exposed the basal elements of the legs, otherwise rarely seen. The specimen has a large, prominent ovipositor, which is preserved on the specimen at the right; it is badly crushed, however, and its shape poorly defined. Some terga with pointed angles, and sterna with rounded angles, are seen detached and lying between the two nymphs. Original from the Upper Coal Measures at Lawrence, Kan.

PLATE LXXVII.

Illustrations numbered from left to right, the first column at the top of the plate being numbers 1 to 4.

FIGS. 1-2.—*Etoblattina* sp. Hind wing. University of Kansas collection, No. 62.

FIG. 3.—*Etoblattina* sp. Hind wing. University of Kansas collection, No. 173.

FIG. 4.—*Schizoblattina multinervia*. Author's collection, No. 4.

FIG. 5.—*Etoblattina* sp. Hind wing. University of Kansas collection, No. 95.

FIG. 6.—*Spiloblattina maledicta*. University of Kansas collection, No. 37.

FIG. 7.—*Spiloblattina maledicta*. Hind wing. University of Kansas collection, No. 132.

FIG. 8.—*Spiloblattina maledicta*. University of Kansas collection, No. 93.

FIG. 9.—*Etoblattina coriacea*. University of Kansas collection, No. 115.

FIG. 10.—*Gerablattina arcuata*. University of Kansas collection, No. 22.

Figures 1, 3 and 4 two and one-half times natural size; figures 2, 5, 6, 7, 8, 9 and 10 twice natural size. All specimens of this plate are from the Le Roy shales, Lawrence, Kan.

PLATE LXXVIII.

FIG. 1.—*Etoblattina scudderi* Sellards. Yale Museum. Enlarged.

FIG. 2.—Same species. Yale Museum. Enlarged.

FIG. 3.—*Etoblattina occidentalis* Scudder. University of Kansas collection, No. 8. 3½ times natural size.

FIG. 4.—*Etoblattina scudderi* Sellards. Hind wing. University of Kansas collection, No. 203. Enlarged.

PLATE LXXIX.

FIG. 1.—*Etoblattina obscura* sp. n. Yale Museum. Enlarged.

FIG. 2.—*Etoblattina obscura* sp. n. Yale Museum. Enlarged.

FIG. 3.—*Etoblattina fulva* sp. n. University of Kansas collection, No. 130. 3¼ times natural size.

FIG. 4.—*Etoblattina occidentalis* Scudder. University of Kansas collection, No. 146. Twice natural size.

PLATE LXXX.

FIG. 1.—*Spiloblattina maledicta* Scudder. Yale Museum. Enlarged.

FIG. 2.—*Etoblattina brevi-cubitalis* sp. n. University of Kansas collection, No. 19. Three times natural size.

FIG. 3.—*Spiloblattina curvata* sp. n. University of Kansas collection, No. 56. Three times natural size.

FIG. 4.—*Etoblattina* sp. Hind wing. University of Kansas collection, No. 175. Three and one-fourth times natural size.

PLATE LXXXI.

FIG. 1.—*Spiloblattina lineata* sp. n. University of Kansas collection, No. 16. Enlarged.

FIG. 2.—*Etoblattina obscura* sp. n. Yale Museum. Enlarged.

FIG. 3.—*Etoblattina fulva* sp. n. University of Kansas collection, Enlarged.

FIG. 4.—*Etoblattina obscura* sp. n. University of Kansas collection, No. 119. Two and one-half times natural size.

FIG. 5.—*Promylacris radialis* sp. n. University of Kansas collection, No. 88. Three times natural size.

FIG. 6.—*Etoblattina fulva* sp. n. University of Kansas collection, No. 142. Two and one-half times natural size.

PLATE LXXXII.

FIG. 1.—*Etoblattina savagi* sp. n. University of Kansas collection, No. 57. Three and one-half times natural size.

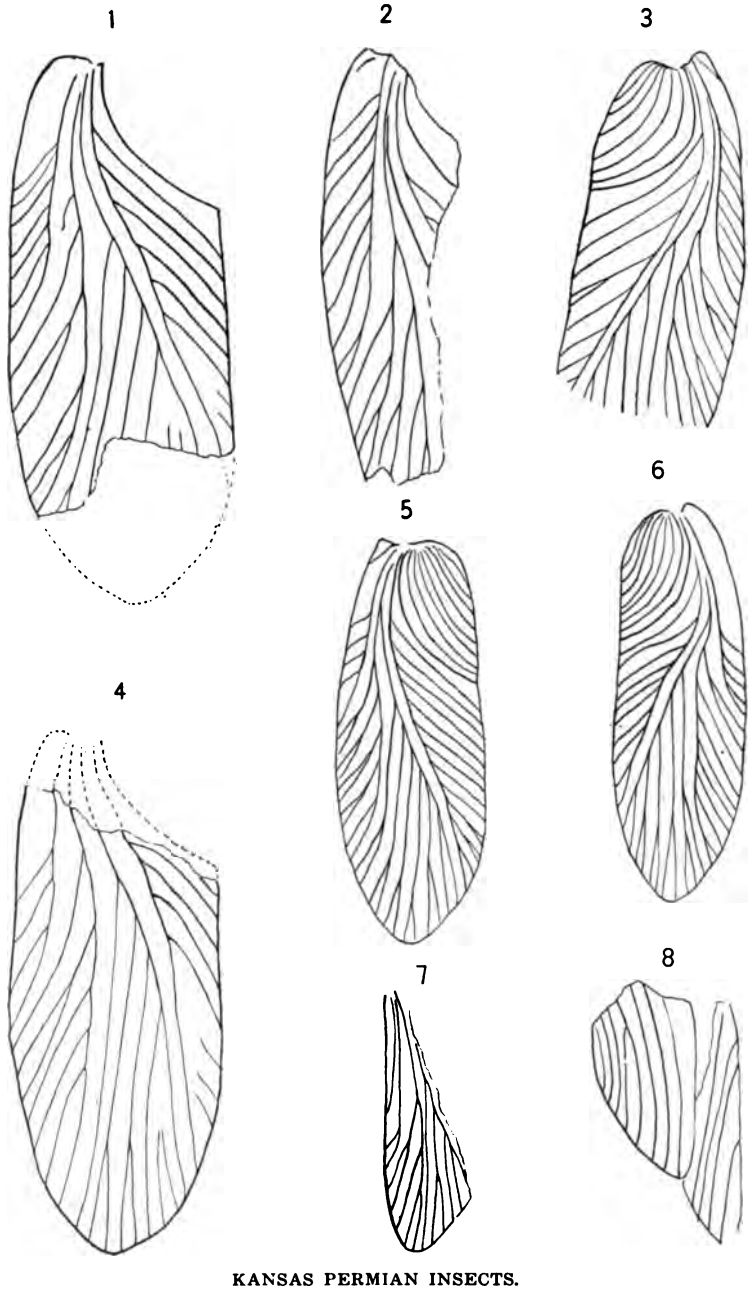
FIG. 2.—*Mylacris latissima* sp. n. University of Kansas collection, No. 36. Three and one-fourth times natural size.

FIG. 3.—Detached wing of nymph. University of Kansas collection, No. 74. Three and one-fourth times natural size.

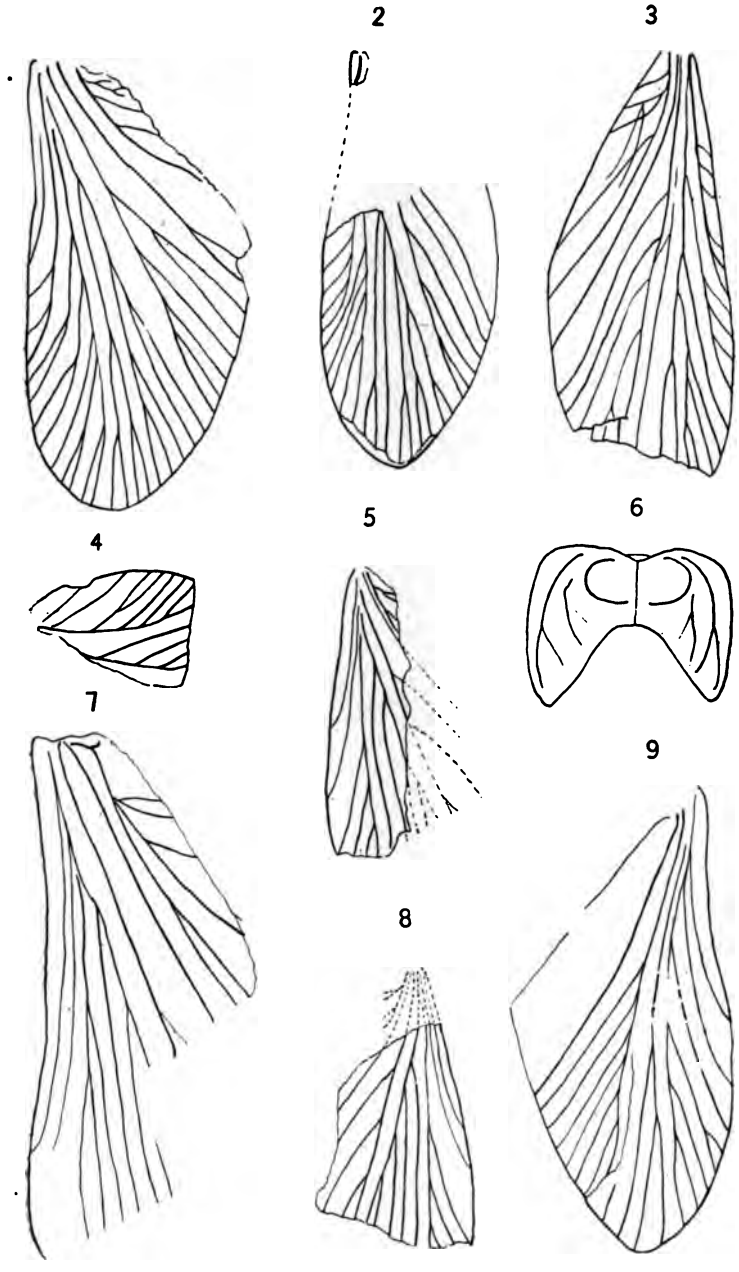
FIG. 4.—*Gerablattina arctuata* Sellards. University of Kansas collection, No. 170. Three times natural size.

PLATE LXXXIII.

FIGS. 1, 2.—*Etoblattina obscura* sp. n. University of Kansas collection, No. 156. Four times natural size.



KANSAS PERMIAN INSECTS.



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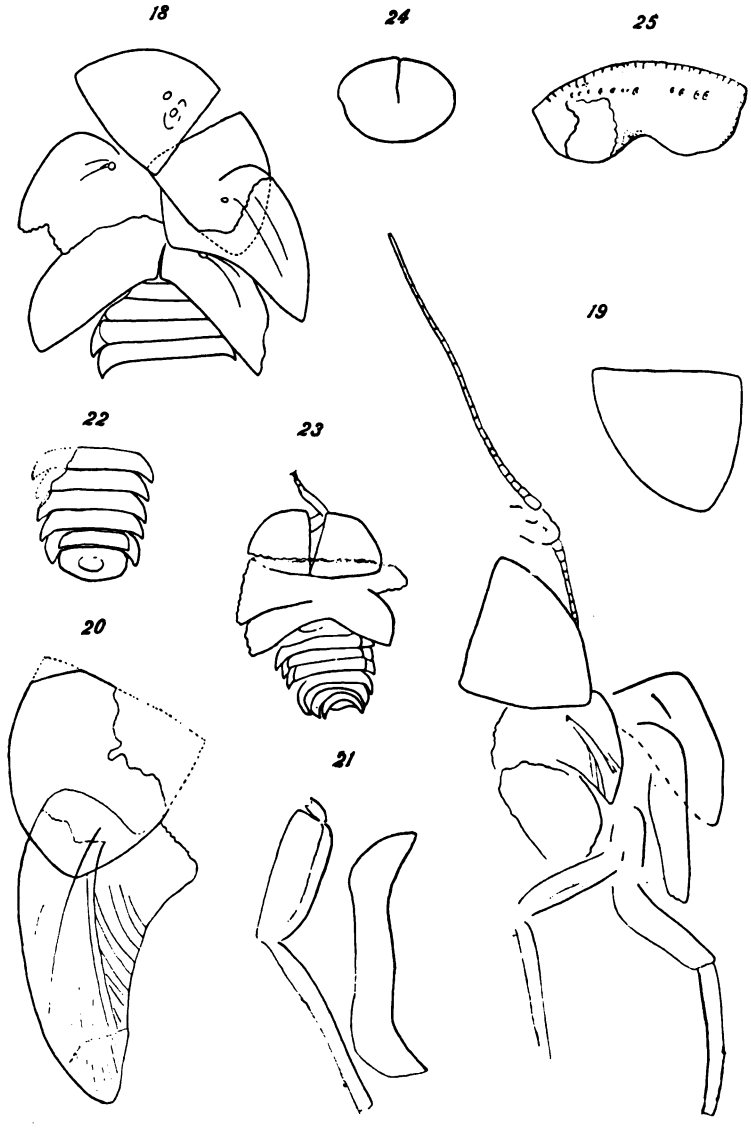
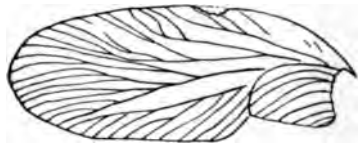


KANSAS COAL MEASURE INSECTS.

26



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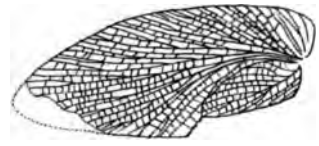

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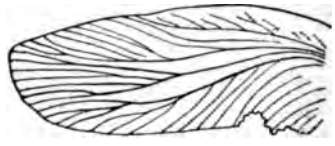

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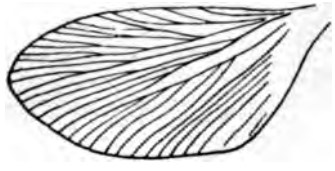

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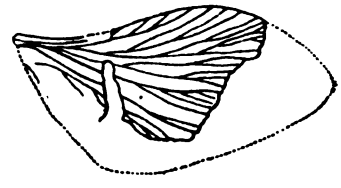

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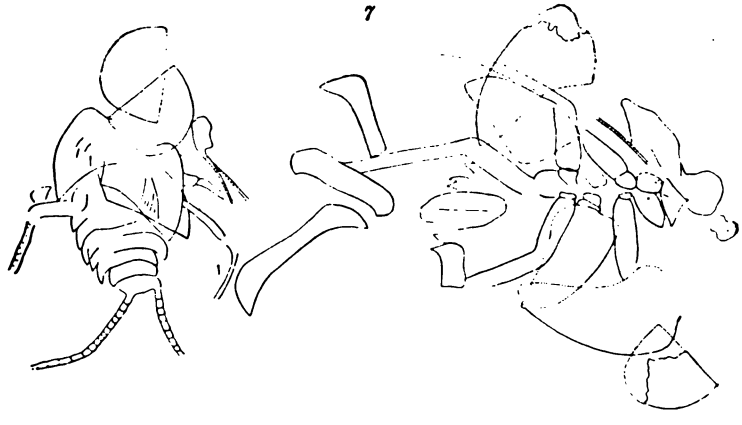
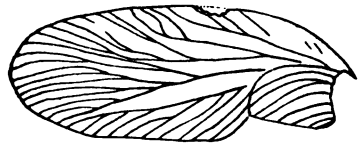


KANSAS COAL MEASURE INSECTS.

26



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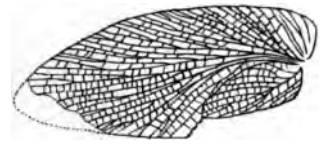

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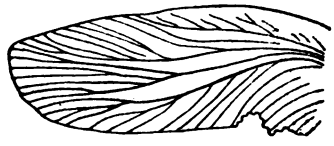

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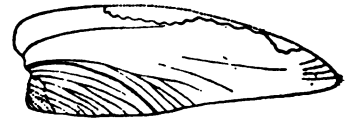

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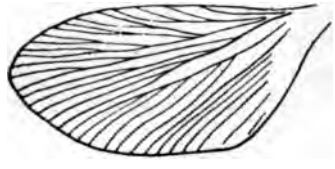

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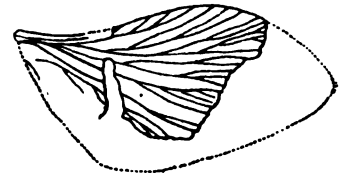

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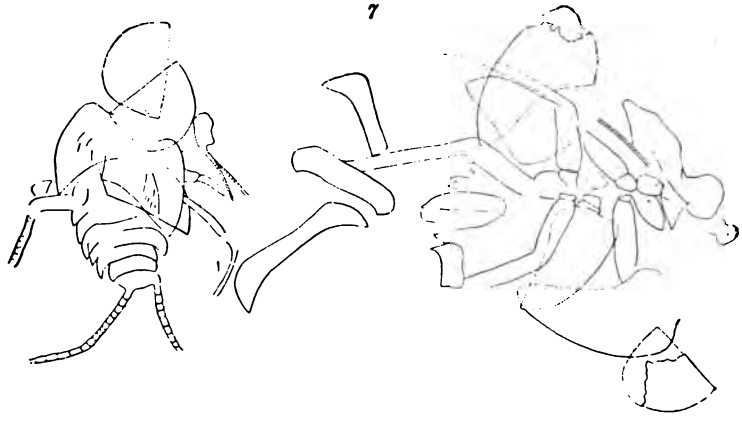

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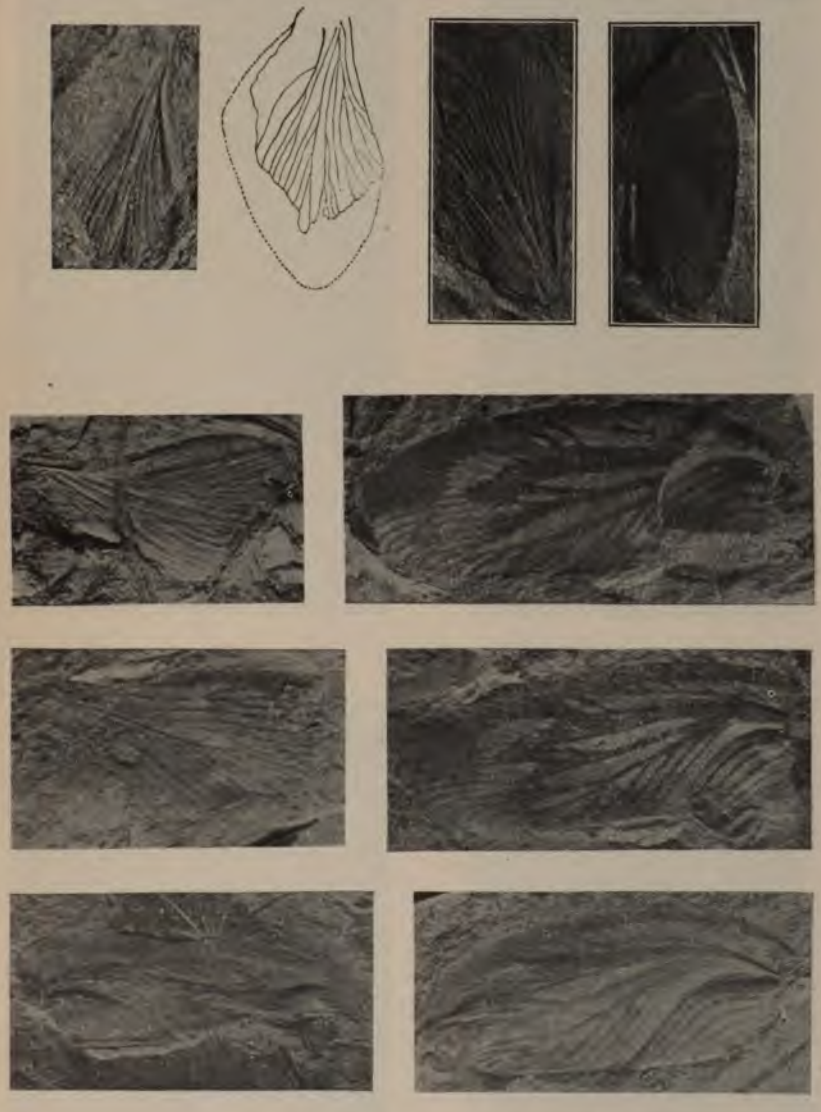

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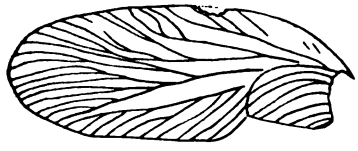

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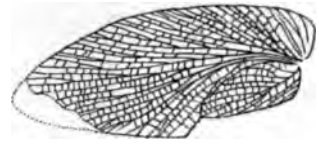

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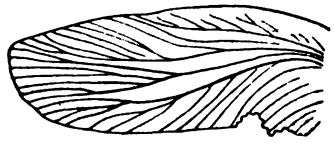

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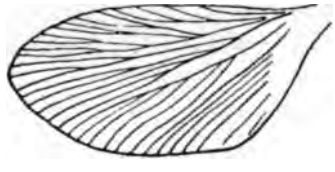

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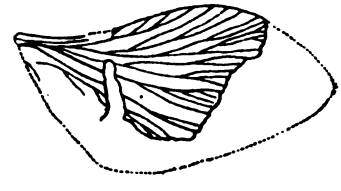

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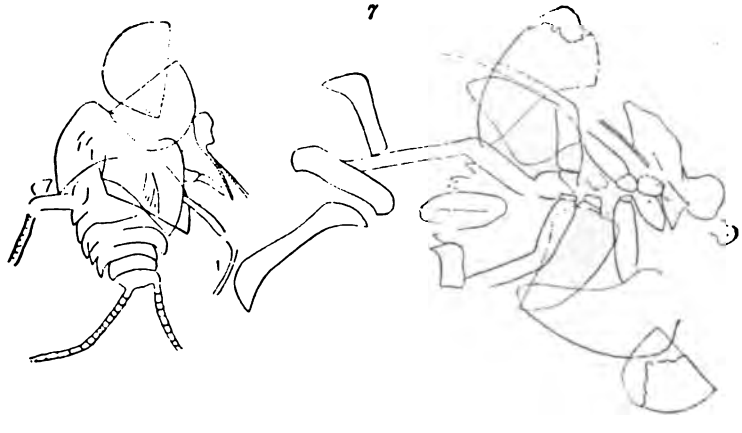

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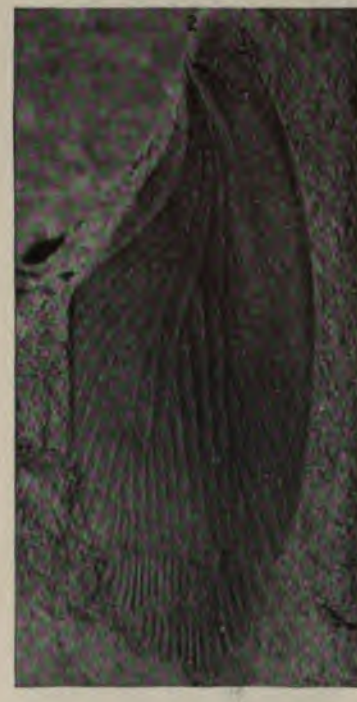

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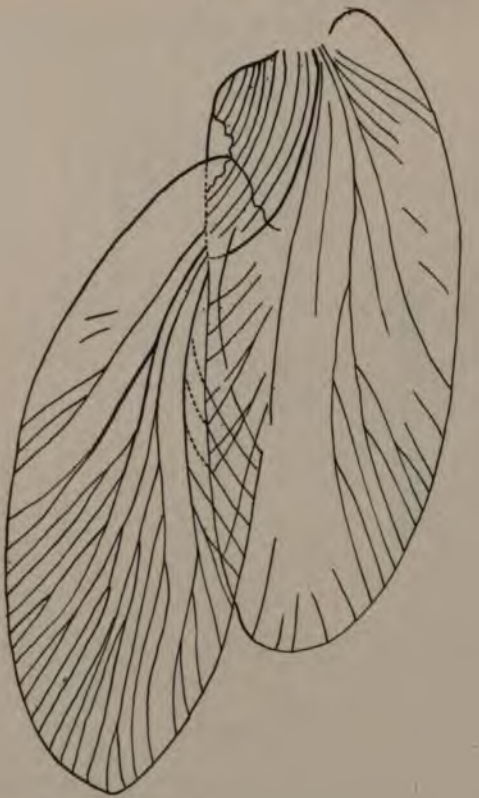

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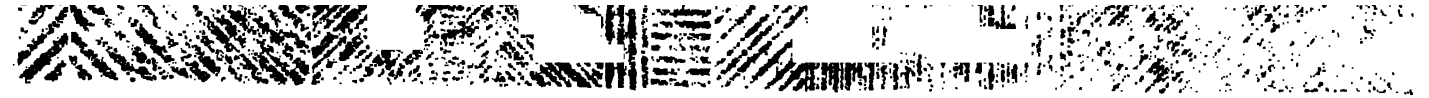
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